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THE UNIVERSITY OF ALBERTA

Greywater Characterization & Treatment for Isolated Northern Communities

by

SHAKUNTALA RANIGA

(C)

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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IN

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ABSTRACT

Waste disposal methods in the Arctic environment create many problems due to soil conditions and extreme climate that are not found in southern climates. Most communities in the Northwest Territories use 'honey-bags' for toilet wastes, which are collected and disposed of onto the land at a dump. Greywater, i.e. wastewater from the kitchen, bathroom and laundry is discharged directly onto the ground surrounding houses.

Although greywater characteristics have been reported in the literature, information was not available on greywater generated in the Northwest Territories. An evaluation program was designed to assess the nature of the greywater for an isolated northern community. Samples from a site in Whale Cove were used in this investigation. The characterisation included measurements of total coliforms, fecal coliforms, fecal streptococci, total organic carbon, suspended solids, total and ortho phosphates, nitrates and ammonia. This greywater contained significant quantities of coliform organisms as well as organic carbon, suspended solids, phosphates and ammonia. Presence of large numbers of coliform organisms indicated the potential for pathogen occurrence.

In order to develop measures to prevent any potential adverse health and environmental effects of this wastewater, a treatment system involving sand filtration and disinfection was evaluated. Samples of greywater from a site

in Edmonton were used in treatment experiments.

The results of this investigation provide an estimate of the pollutional potential of greywater. Sand filtration and chlorination appear to be a practical solution for greywater treatment.

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LIST OF TERMS

The following symbols are used in this thesis:

1. BOD_5 = 5-day biochemical oxygen demand
2. c/L = coulomb per litre
3. COD = chemical oxygen demand
4. DS = dissolved solids
5. Fecal coli. = fecal coliforms
6. FDS = filtered dissolved solids
7. Fecal strep. = fecal streptococci
8. MPN = most probable number
9. NH_3-N = ammonia nitrogen
10. NO_3-N = nitrate nitrogen
11. Ortho-PO_4 = ortho phosphate
12. S. Solids = suspended solids
13. TFS = total filtered solids
14. TKN = total kjedahl nitrogen
15. TOC = total organic carbon
16. Total coli = total coliforms
17. Total-PO_4 = total phosphate
18. TS = total solids
19. TVS = total volatile solids
20. VDS = volatile dissolved solids

I. INTRODUCTION

The Canadian Arctic is an enormous, sparsely populated land. The political boundaries of the Yukon and Northwest Territories (N.W.T.) contain most of the Canadian Arctic. This area of 3.9 million square kilometers, of which 140,000 is fresh water, contain a total population of some 50,000 people, chiefly inhabiting the southern latitutes (Watmore, 1971). Waste disposal methods in the Arctic environment create many problems that are not found in southern climates. In addition, economic resources often do not exist to support central sewerage systems for residential dwellings in isolated northern communities. The management of wastewater discharged from single family dwellings which are not connected to central sewerage systems is a major problem throughout the North.

For many years, subsurface soil disposal via the conventional septic tank-soil absorption system has been the primary method for disposal of wastewater in unsewered locations. Unfortunately, most of the land area in the N.W.T. is simply unsuitable for on site treatment and disposal by the septic tank system due to poor soil conditions and permafrost.

Permafrost is defined as the thermal condition of earth materials such as soil and rock whereby temperatures remain below $0^{0}C$ continuously. Thus, permafrost means ground that remains frozen throughout the annual cycle of seasons. The extent of the discontinuous and continucus permafrost zones

in Canada has been generally determined during the past 10 years, although detailed local information is still sparse in all but a few areas. Continuous permafrost is permafrost consistent throughout the region, whereas discontinuous permafrost is permafrost intermingled with unfrozen ground. Permafrost varies in thickness from a few centimeters or meters at the southern limits to about 60-90 m at the boundary of the continuous zone.

Poor drainage is a typical condition of permafrost terrain because of the presence of impervious frozen ground at shallow depth, even in summer. Saturated ground conditions in summer and a frozen surface in winter cause infiltration rates to drop to as low as zero, thus disallowing the use of conventional septic tank-soil absorption treatment systems for wastewater. Alternate systems need to be developed to prevent health hazards from occurring. The lack of adequate wastewater disposal systems for problem soil areas has caused concern for public health and environmental quality. Several alternate treatment systems whose applications are not dependent on site soil conditions are under investigation (Otis *et al.*, 1975; Sauer *et al.*, 1976; Ziebel *et al.*, 1974; Wei & Heinke, 1975; Bennett *et al.*, 1975). One alternative that appears to offer the greatest potential is waste segregation. Basically this approach involves separation of toilet wastes (black water) and the household wastes (greywater) to facilitate their separate treatment and disposal.

In much of the north, piped water supply systems are not available. This may be largely attributed to piped systems being subject to damage from freezing in permafrost and cold-dominated sites. The construction and operation of insulated, heat-sensitive and dependable systems can impose severe engineering, logistic and economic constraints. The communities to be served in the N.W.T. are very small, generally less than 1000 persons having little or no tax revenue or skilled labor.

There is no doubt that for permanent communities a piped, buried water distribution and sewage collection system is desirable from both a public health and social perspective. However, lack of engineering design information, adequate insulation materials, transportation problems, uncertain economics, sparsely populated and isolated settlements have contributed to the use of alternate solutions.

Lack of piped water supply precludes the use of flush toilets. Hence people rely on "honey-bags" for toilet wastes and thereby segregating greywater. Even with a trucked water system, flush toilets are too wasteful so waste segregation must be maintained. The toilet wastes in honey bags are either dumped indiscriminately on the ground, or to empty barrels which are hauled away by truck. Greywater is generally discharged onto the ground outside houses by a pipe leading directly from kitchen sink and bathroom. Greywater represents all the wastewater produced in a

household other than toilet wastes and includes kitchen, dishwasher, laundry, shower/bath and bathroom sink wastewater.

Greywater is more amenable to treatment for ultimate surface disposal because toilet paper and feces, both soil clogging materials, have been eliminated. The total wastewater flow is decreased by about 40% if greywater is segregated (Laak, 1977). It is believed that the probable potential health hazard from excreted pathogenic organisms would be lower for greywater; however laundering of soiled diapers is a direct source of fecal matter in greywater.

The character of waste flows from individual households can have a profound effect on the performance of individual household treatment and final disposal methods. Various water use events within a home create an intermittent flow pattern of wastes that vary widely in strength and volume. In order to study and improve individual treatment and disposal alternatives effectively, the quantitative and qualitative characteristic of household wastewater must be understood.

The purpose of this study was to adequately characterise greywater both quantitatively and qualitatively. Based on the information obtained, the study attempted to evaluate the feasibility of treating greywater to reduce any potential adverse health and environmental effects due to greywater disposal.

A. SCOPE OF STUDY

To comprehensively investigate the feasibility of treating greywater, to reduce any potential adverse health and environmental effects, the following problems were explored:

1. chemical and biological characteristics of greywater.
2. effluent quality that could be produced by selected treatment processes; and
3. reliability of a treatment scheme.

The major concern with a greywater treatment system is minimizing the amount of homeowner operation and maintenance necessary while insuring a reliable, effective system.

Chapter II contains an extensive literature survey to establish the current practices of treating greywater, including a detailed analysis of its character both qualitatively and quantitatively. Chapter III presents a discussion of the management of greywater from residential dwellings in isolated communities in the N.W.T. The procedures used to characterize greywater are outlined in chapter IV. Also included in chapter IV are the results of laboratory research and a discussion of their meaning. Chapter V contains the procedures used to evaluate the effectiveness of the treatment process studied and an analysis of the feasibility of treating greywater in relation to results of the investigation. Conclusions and recommendations for further study are presented in chapters VI and VII, respectively.

II. REVIEW OF PREVIOUS WORK

A. HEALTH IMPLICATIONS OF GREYWATER MANAGEMENT

Many microorganisms and viruses that occur in water produce diseases in man. Pathogenic organisms found in wastewater are discharged by human beings who are infected with disease or who are carriers of a particular disease. The usual bacterial pathogenic organisms that may be excreted by man cause diseases of the gastrointestinal tract, such as typhoid and paratyphoid fever, dysentery, diarrhea and cholera. Because these organisms are highly infectious, they are responsible for many thousands of deaths each year in areas with poor sanitation, especially in the tropics.

In attempting to assess the hazards in drinking water it is important to know how many viable pathogenic cells are necessary to initiate an infection. McCullough and Eisele (1951) found that a dose of 10^6-10^8 salmonellae per person was necessary for most strains, although 10^5 cells of some strains could initiate infection. Some enteric pathogens are highly virulent, causing infection when relatively few cells are adminstered. For example, a dose of 10^3 *Shigella dysenteriae* and of *S. flexneri* can cause infection. (Levine *et al.*, 1973; Dupont *et al.*, 1972) Other pathogens require large numbers to infect, for example, a dose of 10^7 *Salmonella typhosa* per person (Hornick, 1970) and a dose of 10^6- 10^8 of *Vibrio cholerae* per person. (Cash *et al.*, 1974)

The infecting dose varies with age and general health of the host population. Infants and the aged may be particularly susceptible.

In normal hosts pathogenic enteric bacteria must be ingested in numbers(10^4-10^6 or more organisms) sufficient to overgrow the normal flora of the intestine completely before disease occurs. In compromised hosts, however, and perhaps in some normal hosts as well, the ingestion of small numbers of some of these pathogens may induce disease. Thus, the presence of even a small number of enteric pathogens in a consumed water may not be innocuous. Also, an innocuous situation can be converted into one that is hazardous. For example, if water that contains a small number of pathogenic enteric bacteria is used in the preparation of an infant's formula and the prepared formula remains at room temperature for several hours before feeding, the few pathogens originally present may multiply to disease producing doses by the time the formula is fed. Waters that contain small numbers of pathogenic enteric bacteria may also be used to reconstitute dehydrated foods (such as milk powder) and in the preparations of custards and other foodstuffs that are not cooked before they are eaten. Moreover, the presence of enteric viruses in water, must always be judged to be a potential threat to health.

The smallest numbers of infective virions detected in a water that is consumed constitutes a potential direct risk of infection to the consumer. The risk of disease is

probably not great when such small numbers of virions are ingested, but individuals so infected often excrete large numbers of virions in their feces. The risk of disease in contacts of those who are infected by ingestion of contaminated water, therefore is relatively great because of the large numbers of virions that the contact may ingest.

The diseases that may be borne by water include cholera, dysentery, infectious hepatitis, schistosomiasis, typhoid, leptospirosis, salmonellosis, tularemia, poliomyelitis and tuberculosis. The access of fecal pollution to a water course or a water supply may add a variety of intestinal pathogens. The most common waterborne pathogens include Salmonella, Shigella, enteropathogenic E.coli, Vibrio, Mycobacterium and human enteroviruses. (Bell,1975)

Enteric organisms, that is the gram negative bacilli that normally colonize the intestinal tract, have become increasingly important in human disease. The genera Salmonella, Shigella, certain strains of Escherichia coli and Yersinia are pathogens that can cause serious intestinal diseases. The remaining enterics are opportunists which under normal circumstances are either inconsequential or beneficial to man. However, in an appropriately altered or debilitated host, opportunist organisms can cause disease.

Salmonella infection is almost always due to the ingestion of contaminated materials. The organisms enter the tissues from the intestines. There are three main types of

clinical manifestations of Salmonella infection, namely, enteric fever, gastroenteritis, and septicemia. Among the enteric fevers the classic example is typhoid fever.

The source of all Salmonella infection is the reservoir of organisms living in the tissues of human beings or animals. Infection occurs through food, milk or water contaminated with infected feces or urine or by the actual ingestion of the infected animal tissues. The hosts which harbor the organisms may be clinically recognized cases, sick animals or carriers.

The natural habitat of Shigella is the gastrointestinal tract of man. Thus the only important source of infection in man is the human host. In man, these organisms may cause a fulminating case of classic dysentery, a mild diarrhea or perhaps most frequently an inapparent or subclinical infection following the oral introduction of the specific organisms. Because of this wide variation in severity of clinical symptoms the term "shigellosis" is often applied to infections caused by this group of organisms. The disease is spread from person to person by a variety of methods. Contamination of human fingers with fecal material containing dysentery bacilli is the most common mode of transmission. Contamination of lavatory seats is another important factor. The disease can also spread indirectly through contaminated water and food supplies.

The development of a true carrier state is of rare occurrence, perhaps due to the fact that dysentery bacilli

only invade the intestine and show no tendency to invade the biliery tract. Clinical attack rates are higher in children as compared with adults in the same community.

Escherichia coli is the predominant organism in the intestinal canal of man. The organisms gain entrance to the intestinal canal shortly after birth and persist throughout life. Many, if not all, members may show opportunistic pathogenicity. A limited number of well defined serotypes is closely associated with certain infectious enteric diseases in human infants and young of other animals. There are usually mechanisms provided whereby the newborne may resist bacterial invasion and adjust itself to an equitable host-parasite relationship. This relationship may be upset by various factors. The clinical picture represents in infants a profuse diarrhoea, high temperature, dehydration and prostration often associated with a septicaemia. E. coli organisms may be found in the bone marrow and blood stream. In adult human beings E.coli may invade the appendix, gall bladder, peritoneal cavity, kidneys and the urinary bladder. It has been shown that epidemic diarrhoea caused by certain species serotypes of E.coli may be introduced by carriers. (Cooper et al., 1955)

Vibrios commonly are found in estuarine, coastal and deep ocean water. However, many freshwater Vibrio species also have been identified. The salt requiring and freshwater Vibrios include species pathogenic for man, for example, V. parahaemolyticus and V. cholerae, respectively. Cholera has

been recognized as a waterborne disease of man since the turn of the century. The infectious agent may enter water directly from the infected host or indirectly via wastewater from areas inhabited by clinical cases of cholera, persons in the incubation stage, or healthy carriers.

Infection is acquired either by the ingestion of organisms present in contaminated water or to a lesser degree contaminated vegetables and fruits or from a cholera patient by direct contact. The bacteria multiply in the small intestine and because the organism autolyses very readily considerable amounts of endotoxin are liberated during growth. Cholera is an acute infectious disease characterized by abrupt onset, vomiting, extraordinary diarrhea, muscular cramps and other signs of dehydration, subnormal temperatures, fall of blood pressure, suppression of urine and rapid collapse. Survival of cholera Vibrios outside the host is not of long duration. The organisms remain viable in stools and in river water up to 17 days (Solytys, 1963).

Outbreaks in England and Germany are very good examples of the role of water in the spread of cholera. One of the epidemics in England, known as the "Broad Street Pump" epidemic in London was shown to be spread from one person to another at the pump. By removing the handle of the pump the epidemic was terminated. The disease is now found only on the Asian continent. There has been no cholera in America since 1892 and in Europe since 1925. Cholera is a disease

which occurs only under the most deplorable sanitary conditions. Adequate sewage disposal and proper supervision of water supplies make large-scale epidemics of cholera impossible.

Pseudomonas aeruginosa, while it is often considered to be an ubiquitous bacterial inhabitant of surface waters and soil, appears to enter the environment mainly with human fecal wastes or with the fecal wastes of animals associated with man. It is said to be shed by approximately 15% of all persons (Ziebel et al., 1974). Pseudomonas aeruginosa is an opportunistic pathogen of man and animals which may be spread by water. Gastrointestinal infections with Pseudomonas aeruginosa have been documented, particularly in infants. There is some evidence that such infections can be caused by consumption of contaminated foods or water. Lartigau (1898) first described two outbreaks of gastroenteritis involving 15 individuals of whom 4 died. Pseudomonas aeruginosa was isolated from fecal material and from each of 5 well waters used by the individuals involved.

In addition to the enteric (intestinal) organisms, non-enteric organisms such as those discharged in sputum, and washed from skin can be pathogeinic to man. For example, Streptococci are primarily found in the human upper respiratory and intestinal tracts, and can also be present on the skin, around the anus and in the vagina and cervix. Streptococci infections in man are usually initiated by an apparently healthy carrier, when conditions become favorable

for the propagation of the infecting agent. The infections range from pharyngitis with an acute onset, to the more insidious postinfection sequelae such as rheumatic fever.

Pathogenic Staphylococci are found on the skin and in the nose and are carried on various mucocuteneous surfaces of humans from birth until death. Human beings become infected only when his susceptibility is appreciably affected. Staphylococci may produce a wide range of infections, including pustules of hair follicles or sweat glands, meningitis, endocarditis, pericarditis, pyelonephritis, enterocolitis, osteomyelitis and wound infections. The pathogens washed from skin of an infected person can be transmitted to another person coming in contact with waste washwater.

Wastewater is a possible mode of transmission of Mycobacterium tuberculosis which was isolated from wastewater and polluted streams (Laird et al., 1913). Tubercle bacilli have been detected in the untreated and treated sewage discharges of sanatoria (Jensen, 1954). Cases of tuberculosis in children who had fallen into river contaminated with sewage, have been reported (Miller and Anderson, 1954). Skin infections caused by Mycobacteria in swimming pools and in natural bathing waters have also been reported (Schaefer and Davis, 1961).

Tubercle bacilli can persist in the aquatic environment for weeks. Rhines (1935) demonstrated the survival of the avian strain of tubercle bacilli for 73 days in raw sewage

and estuarine water. Low water temperature and available organic nutrients are the two important factors influencing prolonged survival of the pathogenic Mycobacteria (Rudolfs et al., 1950).

Humans are the only established source of M. tuberculosis. The organisms are mainly transmitted among humans via droplets or aerosols or by direct contact. The usual portal of entry is the lung but the disease may spread to other organs, for example, larynx, lymph nodes and intestinal tract.

M. tuberculosis has a degree of increased resistance to chemical agents, particularly to chlorine and quaternary ammonium compounds, and it persists for extended periods in dried sputum. Thus, washwater from a bathroom sink is a potential mode of transmission for M. tuberculosis. However, phenolics and iodides are effective disinfectants for the tubercle bacillus (Slack & Snyder, 1978).

In addition to bacteria as infectious agents that are potentially waterborne, there are viruses that could contaminate water. The infectious hepatitis virus deserves special attention since it has been definitely recognized as a waterborne pathogen. The ecology of enteric viruses is generally governed by the season of the year and by the socioeconomic level of the population. The viruses are shed in large quantities in feces of even healthy carriers and their numbers in raw municipal sewage may range from 10^3 to more than 10^5/L (Bitton, 1978). These viral pathogens may

survive sewage treatment operations and come into contact with man via food or water. Unfortunately, the virus that causes infectious hepatitis has not yet been isolated. Most of the virus survival studies have used poliovirus as a model and information is still lacking on the behaviour of the elusive virus that causes infectious hepatitis. Since the causative virus has not been cultivated in cell culture, all available evidence about the transmission of infectious hepatitis by polluted water is epidemiologic.

Infections may result from exposure of oral, ocular, nasopharygeal and abraded skin surfaces to viruses. Contamination of water with human viruses usually results from pollution by feces or urine, but shedding of virus from respiratory, genital or ocular sources into bath and washwater occurs, as well.

Of the diseases mentioned above, infectious hepatitis, shigellosis, gastroenteritis, salmonellosis, streptococcal sore throats and tuberculosis have been found to occur in the N.W.T. Table II-1 lists the number of cases of each disease reported by the nurses in each community in the N.W.T. for the years 1974-1978. It should be realized, that the table could be incomplete due to inadequate reliability of reporting occurrences of diseases for small isolated communities.

There may be a potential for the transmission of disease by land disposal of wastewater because of the large variety of disease causing microorganisms and parasites that

TABLE II-I

Waterborne Diseases Reported in the Northwest Territories during 1973-1978
(obtained from Infectious Disease Unit, Northwest Territories Region, Medical Services, Edmonton)

Zone	Population (1970)	Population (1977)	Shigella	Salmonella	Gastro-Enteritis (unspecified)	Typhoid	Hepatitis A	Enterovirus
Sachs Harbour	95	168			3			
Tuktoyaktuk	768	697			55		2	
Aklavik	675	700	18		23	1	1	
Inuvik	3500	3100	71	3	139	1	12	1
Ft. McPherson	850	789	31	1	3		4	
Ft. Good Hope	400	376	5					
Ft. Norman	250	279	8	1	37		12	
Ft. Franklin	410	410	29	1	75			
Norman Wells	250	353	1	1	19	—	1	—
TOTAL INUVIK ZONE			163	7	354	2	32	1
Cambridge Bay	420	856		1	21		22	
Coppermine	500	756			1		2	
Spence Bay	125	433	5	1	42		77	2
Pelly Bay	140	255	2		24		3	
Holman Island	180	288			11		4	
Gjoa Haven	100	402	2		27		18	
Ft. Simpson	700	1050	59	27	185		27	1

continued....

TABLE II-1 (continued)

Zone	Population (1970)	Population (1977)	Shigella	Salmonella	Gastro-Enteritis (unspecified)	Typhoid	Hepatitis A	Enterovirus	Enteric E. coli
Ft. Liard	225	253	39	1	107		58		
Ft. Wrigley	130	212	6		26		2		
Ft. Resolution	600	1736	1	2	220		2	2	
Edzo	1300	1319	140	14	78	1	30		
Snowdrift	150	253	2		15		1		
Ft. Smith	2000	2810	46	6	117		25		
Pine Point	1451	550	6	1			3		
Hay River	3500	4018	25	8	1		47		
Ft. Providence	450	607	23	3	50		11		
Yellowknife	6000	9950	83	11	363	—	79	4	—
TOTAL MACKENZIE ZONE			439	75	1288	1	411	9	
Eskimo Point	470	875	13		1		19		
Whale Cove	150	171			57		11		4
Belcher Islands		304	120		61		25		
Baker Lake	900	900			4		83		
Chesterfield In.	250	254					12		
Rankin Inlet	550	840		1			56		
Repulse Bay	200	274	130		152		35		
Coral Harbour	300	425	2	—	45		39		—
TOTAL Keewatin Zone			265	1	320		280		4

continued....

TABLE II-I (continued)

Zone	Population (1970)	Population (1977)	Shigella	Salmonella	Gastro-Enteritis (unspecified)	Typhoid	Hepatitis A	Enterovirus	Enteric E. coli
Arctic Bay	200	353	2		7		1		
Clyde River	370	363	2		79		41		1
Grise Fiord	70	129					8		
Pond Inlet	300	493	22	1	111			17	
Hall Beach	65	312	3		167		71		
Resolute Bay	500	556			44				
Igloolik	530	645	49		87		28	8	
Pangnirtung	620	906	2		26		55	1	
Broughton Island	120	395	5		87		35	30	
Lake Harbour	240	224	1		9		21		
Cape Dorset	480	664	17		163		36	61	
Frobisher Bay	2100	2418	12	4	2		90	36	
Nanisivik	—	265	—	—	40		—	—	—
TOTAL Baffin Zone			115	5	822		386	153	1
TOTAL - N.W.T.			982	88	2784	3	1109	163	5

are present in domestic wastewater. In addition, bacteria have been found to survive for a long period in cold climates and in soils that retain a high amount of moisture (Beard, 1940). Also, high quantities of nutrients are present in wastewater that enhances bacterial survival. Land application of wastewater over long periods of time could result in the accumulation of organisms at the soil surface where they will be concentrated. Runoff from such areas could contaminate surface waters, if not controlled. At present, there is no evidence available to suggest that land disposal of wastewater is a major mode of disease transmission in the N.W.T. However, it is important to note, that the potential for the spread of disease through surface runoff does exist.

Although most of the above diseases are caused by contamination of water with fecal matter, i.e. mainly black water, greywater is capable of harboring pathogens. Particularly, bath and laundry wastewater could add fecal pollution. As well, washwater from bathroom sinks could contain pathogens from people suffering from respiratory illnesses.

Of special interest is the likelihood of encountering pathogenic organisms carried in the wastewater stream from a given household and if so encountered, in what concentrations. Obviously, the ideal approach would be to test for pathogenic microorganisms in water. However, different pathogens occur at different and highly variable

densities in feces and in polluted waters. This variability reflects the intestinal infections prevalent at different times in warm-blooded animal populations. To detect all disease producing organisms, microbiologists would have to perform a variety of complex, time-consuming, and often not fully verified procedures for each sample analyzed. None of the currently available procedures are applicable to routine quantitative isolation of small numbers of pathogens in water. A more expedient approach is to seek a microbial indicator group common to the feces of all warm-blooded animals.

The coliform organisms have long been recognized as suitable microbiological indicators of water quality largely because they occur in relatively large numbers; they are specific, they are relatively resistant to conditions in most water environments and their detection in water is relatively easy and reliable (Buttianx and Mossel, 1961). An indicator of pathogens is ultimately an indicator of possible hazards to public health. Indicator organisms may suggest the presence of feces, domestic sewage, viruses and other pathogens or sufficient numbers of pathogens to produce disease, but they do not necessarily cause disease themselves.

If the coliform group is to be used as an indicator of fecal pollution of water, it is important to know that the coliforms do not lose viability in the water environment faster than pathogenic bacteria, such as Salmonella and

Shigella.

Little information exists on the survival of bacteria in water. McFeters *et al*. (1974) recently reviewed previous work and presented their own data on die-off of intestinal pathogens in well water. They found the die-off rates for pathogens and coliforms to be approximately the same.

Another factor to be considered is the relative sensitivity of coliforms and bacterial pathogens to disinfectants. Although this subject has been little studied recently, the older work (Butterfield *et al*., 1943; Butterfield & Wattie, 1946; Wattie & Chambers, 1943) indicated that there was essentially no diffenence between these different organisms in sensitivity to disinfection. However, viral pathogens survive longer than bacterial pathogens thus, indicating that viruses are more resistant to disinfection than bacteria (Colwell & Hetrick, 1976).

The coliform test is not infallible, however. A negative coliform test result does not rule out the presence of harmful organisms, especially the more hardy viruses. Lanyi *et al*. (1967) isolated *Pseudomonas aeruginosa* from drinking water samples regarded as satisfactory on the basis of the coliform count.

Smith *et al*. (1977) found shower wastes aboard a Great Lakes vessel to contain >1,000/100 mL of *Ps. aeruginosa*. This organism is a pathogen of particular concern to man because it is highly resistant to antibacterial agents. This organism may be found in wound infections, and in eye and

ear infections. Ear infections may lead to complications, such as abscess of the brain, mastoiditis, thrombophlebitis of the lateral sinus, and sometimes meningitis. Also it may play and important role in gastrointestinal disturbances. (Grabow, 1970).

The washwater diseases (mostly skin, eye, and ear infections but also including some very rare and very serious nervous system infections) are indirectly, if at all, related to fecal contamination. Thus, it must be recognized that there are diseases which may be contracted by water contact for which the fecal indicators are extremely poor, if not irrelevant.

Total coliform as a fecal indicator is not valid because it includes organisms of nonfecal origin. The fecal coliform group is a better fecal indicator system and a part of the total coliform group. Yet, the total coliform group is useful in disinfected waters because it comprises more organisms than the fecal coliform group and thereby survives longer in a disinfected water, adding a measure of safety as an indicator of more resistant pathogens. However, even when indicator bacteria are absent from a water, one cannot be certain that viruses are also absent. The total coliform and fecal coliform tests have been paramount in the bacteriological monitoring of water quality. A classic failure of the coliforms as indicators of fecal pollution occurred in Riverside, California, in 1965 when a waterborne outbreak of Salmonella typhimurium infections afflicted more

than 16,000 persons (Condit and Stone, 1965). Although Salmonella typhimurium was recovered from the incriminated water supply, fecal coliforms were not. Thus, rigid reliance upon a single indicator group may lead to a false assurance of the bacterial safety of a water.

The use of fecal streptococci as indicator of fecal pollution of water has been suggested by various researchers. The advantages of fecal streptococci as pollution indicators arise from their absence from pure waters, virgin soils, and environments having no contact with human and animal life, their persistence without multiplication outside the animal body, and their presence in much greater numbers than pathogens.

Fecal coliforms and other coliforms as well, can multiply in water given sufficient nutrient material. Streptococci do not multiply in polluted waters, giving them a significant advantage over coliform indicators for detecting recent pollution. Fecal streptococci generally have been found to be more persistant than fecal coliforms and are therefore a safer indicator of pollution. Since fecal streptococci survive longer than fecal coliforms, they are a better indicator of viral contamination (Kenner, 1978).

A fully adequate indicator system does not exist for viruses in the water environment. Nor, for that matter, does there exist an indicator system that serves well for pathogenic bacteria in all situations. Usually, the presence

of indicator coliforms, fecal coliforms and fecal streptococci in a water implies the possible presence of viruses and other pathogens.

B. GREYWATER FLOW AND LOADING PATTERN

A summary of the average flow volumes determined by several investigators for household greywater events is presented in Table II-2. As shown, the primary contributors to the greywater flow are the activities of bathing (41.8 L/c/d or 40%) and laundry (37.8 L/c/d or 34%). In total, the greywater generated in a typical residential dwelling was, on the average, 105.2 L/c/d.

Several investigators (Bennet and Linstedt, 1975; Besik, 1973; Haney &Haman, 1967; Laak, 1974; Ligmann, 1972; Siegrist et al., 1976; Wallman, 1972;) have determined the water usage for different household events as a percentage of the total average flow. The results are summarized in Table II-3.

Based on the assumption of four persons per household Bennett and Linstedt (1975) estimated the composition of soap-related wastewater. The bathroom sink was estimated to contribute 20%, bathtub and shower 35%, laundry 40% and dishwater 5% of total wastewater.

For designing a proper treatment system, additional information on patterns or variations in the flow is required, in addition to the volumes of wastewater produced per day. Witt (1974) investigated wastewater flows from 11

TABLE II-2

WATER-USE VOLUMES

	Witt, 1974	Laak, 1974	Bennett & Linstedt I975	Siegrist et al. I976	Ligman et al. I974
	L/c/day	L/c/day	L/c/day	L/c/day	L/c/day
Laundry	127.3	28.0	45.4	39.8	38.0
Bath	81.3	40.1	41.6	37.9	47.5
Dishes	47.5	13.6	26.5	18.6	13.3
Other	-	-	-	30.3	-
TOTAL	256.1	81.7	113.5	126.6	98.8

TABLE II-3

WATER USAGE COMPARISON, (as a percentage)

Usage	U.S. geog. Survey, 1962	Haney & Hamann, 1967	Laak, 1974	Ligmann, 1972	Wallman, 1972	Besik, 1973	Bennett 1975	Siegrist et al. 1976
Toilet	41	45	47	41	27-45	38	33	22
Laundry	4	5	18	19	18	12	27	25
Bath	37	30	21	26	18-36	34	24	23
Kitchen	6	6	9	10	13	10	16	11
Cleaning	3	4	-	1	-	3	-	-
Drinking	5	3	-	3	-	3	-	-
Miscellaneous	4	7	5	0	6	0	-	19
flow L/c/d.	-	-	155.8	171	114-190	-	169.1	163.4

homes in Wisconsin, with the objective of studying contributions made to the volume of wastewater from various events in a home on a day-to-day basis. The usage patterns throughout the day on an hourly basis was also studied to identify periods of high or low flow and the frequency of the various events contributing to the flow.

Monday was found to have the highest average flows with 187.8 L/c/d while Friday had the lowest with an average of 141.8 L/c/d. Little variation in the flow existed for any of the events except the bath and laundry. Baths showed a significant difference between Friday at 30.4 L/c/d and Saturday at 45.8 L/c/d. The laundry contributed a significantly higher value to the flow on Monday and Tuesday, when compared to other days of the week.

On a typical day, peak water usage occurred during the morning and evening hours producing flows of 161.2 L/c/d. Laundry was largely concentrated in the morning with 63% of flow occurring between 7 a.m. to 2 p.m. Peak flows from baths and showers were most often found in the evening hours between 5 p.m. and midnite although the morning hours of 6-9 a.m. also showed an increase from this event. Dishwashings were measured in 3 peaks following the mealtimes with the largest flow between 5 and 7 p.m.

In a similar study by Siegrist et al. (1976) the vast majority of pollutant mass produced by an average household was found to be generated between the hours of 6 a.m. and 9 p.m. with distinct peaks occuring at 9 a.m., 1 p.m. and 7

p.m.

C. GREYWATER CHEMICAL CHARACTERISTICS

The characteristics of greywater depend on the living habits and personal hygiene. The different cleaning agents, dishwashing, bathing, and other household liquids used by a family will influence the physical, chemical and microbiological characteristics of greywater between families. Thus, averages of representative greywater characteristics must be used cautiously. Tables II-4, II-5, II-6 & II-7 summarize some average characteristics of individual wastewaters as determined from the literature. As shown, the greywater does contain significant concentrations of the pollutants monitored. The kitchen wastewaters primarily contain food residues, dishwashing detergent and wastewater from food preparation which can produce a significant organic contribution. In addition, kitchen wastewaters occasionally contain drain cleaners, scouring cleansers and bleach.

Bathroom greywaters carry shaving wastes, shower/bath waters, soaps, toothpastes and mouthwashes. Laundry contributes body oils and dirt, detergents, and a large volume of water. Rinsing dirty diapers will add to the numbers of coliforms and fecal coliforms.

TABLE II-4

CHARACTERISTICS OF GREY WATER FROM LITERATURE SURVEY

Parameter mg/L	Brandes, 1977 Grey Water Septic Tank	Hypes, 1974 Synthetic Grey Water	Olsson et al, 1968 Bathroom & Kitchen Waste	Bennett, 1975 Bathroom & Laundry Waste
Total PO_4 as P	1.4	19.2	7.8	10.2
Ortho-PO_4 as P	0.17	---	0.24	3.0
S. Solids	162	33	141	183
TOC	125	80	---	---
NH_3-N	1.7	0.15	0.5	0
NO_2-N	0.04	0.29	0.01	---
NO_3-N	0.12		---	---
TKN	11.3	---	6.5	1.3

TABLE II-5

CHARACTERISTICS OF GREY WATER FROM LITERATURE SURVEY

KITCHEN WASTE

Parameter	Siegrist et al, 1976 (mg/L)	Laak 1974 (mg/L)	Witt et al, 1974 (mg/c/d)
Total PO_4 as P	74	12.7	419
Ortho-PO_4 as P	31	-	177
S. Solids	720	-	4111
TOC	880	-	5000
NH_3-N	6	5.44	32.3
NO_2-N	-	-	-
NO_3-N	0.3	0.56	1.8
TKN	74	-	424

TABLE II-6

CHARACTERISTICS OF GREY WATER FROM LITERATURE SURVEY

BATHROOM WASTE

Parameter	Siegrist et al, 1976 (mg/L)	Pancuska, 1975 (mg/L)	Witt et al, 1974 (mg/c/d)
Total PO_4 as P	2	10.0	36
Ortho-PO_4 as P	1	-	21
S. Solids	120	304	2261
TOC	100	103	1749
NH_3-N	2	-	40
NO_2-N	-	-	-
NO_3-N	0.4	-	7.4
TKN	17	11.2	306

TABLE II-7

CHARACTERISTICS OF GREY WATER FROM LITERATURE SURVEY

LAUNDRY WASTE

Parameter	WASH CYCLE		RINSE CYCLE	
	Siegrist et al, 1976 (mg/L)	Witt et al, 1974 (mg/c/d)	Siegrist et al, 1976 (mg/L)	Witt et al, 1974 (mg/c/d)
Total PO_4 as P	57	1602	21	548
Ortho-PO_4 as P	15	411	4.0	112
S. Solids	280	7927	120	3043
TOC	280	7698	100	2605
NH_3-N	0.7	19.4	0.4	11.4
NO_2-N	-	-	-	-
NO_3-N	0.6	17	0.4	10.3
TKN	21	579	6	146

D. GREYWATER MICROBIOLOGICAL CHARACTERISTICS

In surveying literature, microbiological studies have demonstrated that raw greywater does possess a potential for containing pathogenic organisms. Microbiological characteristics reported by several investigators (Bennett and Linstedt, 1975; Brandes, 1977; Hypes, 1974; Siegrist et al., 1976; Olsson et al., 1968;) are presented in Table II-8. As shown, the results demonstrate that a wide range of indicator organisms can be expected in greywater, which in turn indicated a potential for their pathogenic contamination. Siegrist (1977) monitored the greywaters produced in bathroom and from washing clothes, from 6 households over a 2-week period, yielding the results shown in Table II-9. Bath and laundry are the 2 major household activities which possess the potential for contributing pathogenic bacteria to the greywater.

In addition, bacteriological analyses were performed for two common pathogens, Pseudomonas aeruginosa and Staphylococcus aureus. The results are shown in Table II-10, indicating a very low incidence of Ps. aeruginosa. In those samples where it was isolated, the concentrations were always below 20/100 mL. Sa. aureus was not isolated in any of the samples analysed. Based on these results, the pathogenic contamination in these raw bath and laundry wastewaters appear to be fairly insignificant.

However, Smith et al. (1977) found shower wastes aboard a Great Lakes vessel to contain >1,000/100 mL of Ps.

TABLE II-8

Microbiological Characteristics of Grey Water

Parameter	Brandes, 1977 Grey Water Septic tank	Hypes, 1974 Synthetic grey water	Olsson et al, 1968 Bathroom & Kitchen waste	Bennett, 1975 Bathroom & Laundry waste	Olsson et al, 1968 Kitchen waste
Coliforms (#/100ml)	2.4×10^7	1.9×10^7	3.8×10^6	1.5×10^6	3.0×10^7
f. Coliforms (#/100ml)	1.4×10^6	-	9.4×10^5	-	6.1×10^6
f. Strep (#/100ml)	-	-	-	-	-

TABLE II-9

BATHROOM AND LAUNDRY WASTE

Parameter	Siegrist et al, 1976 Bathroom Waste	Olsson et al, 1968 Bathroom Waste	Siegrist et al, 1976 Wash Cycle	Siegrist et al, 1976 Rinse Cycle
coliforms (#/100 mL)	1100	6.1×10^6	1.8×10^4	5.3×10^3
f. coliforms (#/100 mL)	220	9.7×10^5	1.4×10^3	3.2×10^2
f. strep.(#/100 mL)	44	-	2.1×10^2	75

TABLE II-10

PSEUDOMONAS AERUGINOSA AND STAPHYLOCOCCUS AUREUS IN BATH & LAUNDRY WASTE WATER

(Siegrist, 1977)

		BATHING			LAUNDRY		
Pathogen	Home*	Samples	Positive Samples	Highest Value	Samples	Positive Samples	Highest Value
Pseudomonas aeruginosa	N	10	2	2/100 mL	17	5	20/100 mL
	R	1	0	a	4	0	b
	W	10	0	b	5	0	b
Staphylococcus aureus	N	9	0	c	17	0	e
	R	1	0	d	4	0	e
	W	10	0	e	4	0	e

a below detection limit of test which was 2/100 mL

b below detection limit of test which was 20/100 mL

c below detection limit of test which was 10/100 mL for 3 samples & 10^4/100 mL for remaining

d below detection limit of test which was 10^4/100 mL

e below detection limit of test which was 10/100 mL

* N, R, W designate the 3 homes studied.

aeruginosa, a level significantly above the background Ps. aeruginosa count(22/100 ml) in the utility water.

A very limited data base exists for conclusively determining pathogenic content of greywater. Also, very little is known about the concentration of viruses in the total raw wastewater from an individual household. In an attempt to better identify the potential for contamination of household greywater by pathogenic bacteria and viruses, further studies have to be conducted.

In addition to the results shown in Table II-9, Siegrist et al. (1976) obtained several isolates from laundry wash cycle, rinse cycle and bath/shower activity. Sixty-one fecal isolates were obtained from wash and rinse wastewaters and characterised as 65% Escherichia Spp.(mainly E. coli), 27% Klebsiella pneumonia (with the ability to grow at 44.5^{0}C), 5% high temperature Enterobacter aerogenes biotypes, and 2% Citrobacter freundii. Approximately 90% of the 24 fecal coliforms isolates from bath waters were Escherichia Spp. with the remainder, Klebsiella pneumonia. Certain biotypes of the genus Klebsiella are associated mostly with upper respiratory tract and hospital acquired infections. E. coli can cause profuse diarrhea in infants.

A total of 48 Streptococcal isolates were obtained from bath, wash, and rinse wastewater samples. Enterococci made up 38% of these isolates. The majority of bath enterococci were S. faecalis Var. liquefaciens. 22% of Streptococcal isolates were characterised as S. bovis. Other Streptococcal

species generally found on and in the body of animals and man, Viridens and Pyogenic groups, were also isolated.

Many of the above organisms, though associated with animal feces, are often considered to exist in nature and probably have less sanitary significance than other enterococcal species. However, the high incidence of E. coli, Klebsiella spp. and Enterococci especially in wash and rinse wastewaters, indicates that these wastes potentially contain pathogenic organisms.

In a study conducted by Brandes (1977), all the fecal coliforms isolates were found to be E. coli. Since this organism is generally accepted as an indicator of fecal pollution, a potential health hazard could possibly be assigned to greywater.

E. GREYWATER TREATMENT

A number of studies have been conducted on the on-site treatment of household wastewater in rural communities. The septic tank-soil absorption field is the most commonly used system. The system includes septic tank pretreatment followed by subsurface disposal. There are basically six ways to treat and dispose septic tank effluent below the soil's surface: seepage pits, absorption trenches, seepage beds, evapo-transpiration beds, mounds and leaching chambers (Stoner, 1977).

Seepage pits are excavated pits 90-120 cm wide and 180-220 cm deep located about 30 m from the house. These

pits are constructed only in permeable soils. Absorption trenches are the most commonly used treatment method for septic tank effluent. Basically, this method involves distribution of septic tank effluent by perforated pipes or tiles into a gravel bed, where it leaches out into the surrounding soils. Seepage beds are compact leach fields where the bottom of the bed is the primary soil interface. Evapo-transpiration beds evolved from seepage beds. They are shallow beds with gravel at the bottom to provide storage of effluent for eventual evaporation. Plants grow on the soil surface and utilize the wastewater. Mounds are constructed a few feet above the normal grade and are trapezoidal in cross-section. Wastewater is pumped up to the raised absorption field. Leaching chambers are precast concrete structures used in place of absorption trenches. They have open bottoms and are usually about 1.2 m wide, 30 cm high and up to 2.4 m long. Water from a septic tank fills the hollow space under the leaching chamber and is distributed evenly across the soil beneath the chamber.

Otis et al. (1975) investigated several treatment units under laboratory and field conditions as alternatives to the conventional septic tank system to improve effluent quality. The improved effluent quality in turn would enhance soil infiltration and reduce the dependence on soils for final treatment, or eliminate the need for soils in final disposal altogether. They examined:

1. a single-compartmented septic tank

2. a multiple-compartmented septic tank
3. continuous flow-extended aeration units receiving either raw sewage or septic tank effluent
4. batch-extended aeration units receiving raw wastes only and
5. rotating biological disk units.

The results indicate that under laboratory conditions a multi-chambered septic tank appeared to give slightly better treatment than the single-chambered septic tank. Also, aerobic units perform significantly better than the septic tanks. However, under field conditions multiple compartment septic tank have not yet been shown to provide significantly better treatment over the single-compartment tank. Under field conditions, aerobic units yield better treatment than septic tanks, but periodic upsets cause great variability in effluent quality. Nearly complete nitrification was achieved through the aerobic units while ammonia and organic nitrogen were the dominant forms in septic tank effluent.

The conventional septic tank-soil absorption field is not a suitable system of wastewater disposal in many areas, such as those with slowly permeable soils, excessively permeable soils, or soils over shallow bedrock or high ground water. Bouma (1974) suggested an alternate system of above-ground mounds that use the soils ability to absorb and purify wastewater. Mounds are constructed from soil, sand, and gravel and are normally trapezoidal in cross-section. Effluent entering the mound receives treatment in the mound

soil just as it does in properly suited native soil.

However, at some sites, the soils may be totally inadequate as a treatment and disposal medium. In such instances, an on-site wastewater disposal system which is not dependent on soil disposal, but which discharges the treated wastewater to surface waters is necessary.

Sauer et al. (1976) investigated intermittent sand filtration of septic tank and aerobic treatment unit effluents, as an alternative to subsurface disposal for household wastewater treatment. The effluent from the septic tank flowed into a small wet well where a submersible pump intermittently applied the effluent to a sand filter. The filter consisted of 61 cm of sand (effective size of 0.45 mm and uniformity coefficient of 3.0) overlying 20 cm of supporting pea gravel and 20 cm of coarse stone. Since the surface area of the filters was small ranging from 1.45 square meter to 2.90 square meter the hydraulic loading rates of wastewater applied to the filters were relatively high (3 $L/d/cm^2$-2.6 $L/d/cm^2$). The sand filter effluent was collected in perforated pipes laid in the pea gravel and flowed by gravity through a dry-feed chlorinator and finally into a chlorine contact chamber. Hypochlorite tablets containing a minimum of 70% free chlorine were used with detention time ranging from 3 hours to 21 hours. Sauer et al. (1976) has demonstrated significant reductions of BOD_5, suspended solids and indicator organisms with average effluent qualities of 4-10 mg/L for BOD_5, 6-15 mg/L for

suspended solids and 2-61 fecal coliform /100 mL. The septic tank-sand filtered effluent without chlorination showed a BOD_5 of 6-20 mg/L, suspended soilds ranged from 6-22 mg/L, and fecal coliform count was found to be 0.5-9.8 X 10^3/100 mL. Sand-filtration after septic tank or aerobic unit pretreatment of combined wastewater produced a fairly high quality effluent, containing a low concentration of chemical/physical pollutants and indicator bacteria. This improvement in wastewater quality makes it possible for sand filtered effluent to be disinfected and discharged to surface waters.

Brandes et al. (1974) studied phosphorus removal from domestic sewage using different kinds of soil filters. Three column filters of inside diameter 15.2 cm and length of 61 cm were filled with different media. One column contained limestone, a second column contained homogeneous mixture of 50% sand and 50% limestone, and a third column contained a homogenous mixture of 90% sand, 10% red mud. The removal of phosphorus from the three columns was 71%, 76.3% and 96.9%, respectively. The concentration of phosphorus was 0.73 mg/L in the effluent from column three. Also tested were 10 underdrained filter beds 30.5 by 25.4 cm and 10.2 cm deep, filled with different kinds of filtering media. The most effective filter bed was bed number 10 containing 38.1 cm sand and 38.1 cm mixture of clayey silt (35% clay, 57% silt, 8% sand) which contributed to a removal of approximately 99% of BOD_5, 90% of the COD, and 96% of the suspended solids

from sewage and contributed to a relatively high degree of nitrification. Brandes et al. (1974) also found that finer sand appeared to be more effective in removal of fecal coliform organisms. A 1.0 m deep sand filter of an effective grain size D10 = 0.24mm and uniformity coefficient, Cu = 3.9 was able to reduce the concentration of fecal coliform organisms from 2.0 X 10^6/100 mL in the septic tank effluent to 0.03 X 10^6/100 mL in the effluent from the sand filter i.e. 98.5% removal. The concentration of total coliform organism dropped from 19.9 X 10^6/100 mL to 2.3 X 10^6/100 mL(88.4% removal)

Ziebel et al. (1974) showed that a sand filter of an effective grain size(D10 = 0.45mm) and uniformity coefficient of 3.9 was a reduce the fecal coliform organism concentration from 2.3 X 10^4/100 mL of effluent to 4.2 X 10^3/100 mL(81.7% removal). The concentration of total coliforms was found to be 0.13 X 10^6/100 mL(94.6% removal).

Wei and Heinke (1975) conducted a bench scale experiment on the electrolysis of raw domestic wastewater using consumable electrodes of stainless steel and iron. They presented a conceptual design of an electrolytic household wastewater treatment unit for a family of five people. They suggested that an electrolytic waste treatment unit could be an alternative to the septic tank and tile bed system in areas where the latter is not applicable due to poor soil and terrain conditions.

Preliminary experimental data indicated significant

removal of organic carbon and phosphate. A coulomb density of about 500 c/L achieves about 75-80% reduction in non-settleable organic matter. A 80% phosphate removal efficiency was achieved at a low coulomb density of 240 c/L. However, bacterial reduction in the process is small. Another disadvantage to the above system is that it is more expensive than a standard septic tank and tile field, consumes electrical energy and requires periodic replacement of electrodes.

All of the above treatment methods discussed have been investigated and evaluated for combined wastewater.

To improve methods of on-site wastewater management, more emphasis is being placed on waste segregation and separate treatment, especially in developing alternate treatment systems not dependent on site soil conditions. Basically, segregation involves separating the individual water uses within a home into two fractions

1. toilet wastes(blackwater)
2. kitchen, bathroom and laundry wastewaters (greywater).

The removal of toilet wastes from the household wastestream, through non-conventional toilet systems would reduce the wastewater flow volume and pollutant load to that of greywater. This greywater is more amenable to treatment for ultimate surface disposal.

To date, there has been only limited research conducted and experience gained regarding the on-site treatment and disposal of household greywater, especially when considering

on-site surface discharge. The most commonly employed method of greywater treatment and disposal is the conventional septic tank-soil absorption field. Laak (1977) modified the conventional septic tank soil absorption system by designing a greywater pretreatment tank for which the design values were based on total pollutant per capita and mean maximum monthly wastewater flows which are less than for combined wastewater. This tank is smaller in size than conventional septic tank. The design of a greywater pretreatment tank takes into consideration, that greywater is typically 20°C hotter than combined sewage.

Raman and Chakladar (1972) investigated the use of anaerobic upflow filters to reduce soluble BOD_5 loading on sand filters and on leaching fields. The tank effluent entered at the bottom of a filter column through a system of underdrains, flowed upward through a layer of coarse material (for example, gravel) 61 cm to 122 cm deep and was dicharged over a weir or trough at the top. The flows in the filters were intermittent. The mean BOD_5, COD, and suspended solids removal efficiencies were 73%, 57% and 64%, respectively, among the three filters.

Laak (1977) also proposed treating the effluent from upflow filter media with a leaching field system. Compared to a conventional septic tank system, a 40% smaller field length perpendicular to groundwater flow was adequate. Based upon clogging load a 50% smaller interface area was adequate.

Siegrist (1978) studied the performance of a septic-tank sand filtration system for poor site conditions. The system included septic tank pretreatment followed by sand filtration and then surface disposal. The wastewater generated by typical household events was simulated utilizing consumer materials and waste products. The simulated household events were made to occur intermittently during the day. The greywaters were directed to each of two septic tanks of 1892.5 L and 3785 L size. The third septic tank of 3785 L received toilet flush wastewaters in addition to the same greywater. Eight sand filter lysimeters, each having a surface area of about 29 square cm, 61 cm sand, 12 cm peagravel and 18 cm coarse stone were established. The results are presented in tables II-11 and II-12.

Although the concentrations of BOD_5, COD and suspended solids were considerably higher in the raw combined wastewater as compared to the raw greywater, characteristics of the effluents from the two 3785 L septic tanks were essentially the same. Siegrist found that sand filters receiving 30 cm/day of greywater septic tank effluent yielded filter run lengths over twice as long, processed over twice as much wastewater and removed over 140% more BOD_5 and 60% more suspended solids than did similar filters receiving combined wastewater septic tank effluent. Intermittent sand filtration of greywater septic tank effluent through 60 cm of medium sand yielded effluents low in BOD_5 and suspended solids, almost completely nitrified

TABLE II-11

SEPTIC TANK EFFLUENT QUALITY, mg/L
(Siegrist, 1978)

Parameter	GREY WATER			COMBINED WASTE WATER	
	Influent[a]	1892 L tank effluent	3785 L tank effluent	Influent	3785 L tank effluent
BOD_5[b]	220	101	62	260	55
COD	420	236	171	730	169
TSS	110	47	46	410	46
VSS	-	37	34	-	33
Total-N	12	6.5	7.7	80	79
NH_3-N	-	1.4	2.1	-	54
Total-PO_4 as P	44	44	40	57	43
Ortho-PO_4 as P	-	34	34	-	36
Flow (L/d)	484	-	-	711	-

a Based on periodic analyses of the simulated waste water constituents as well as daily flow composited samples.

b Based on 10 sample analyses, soluble BOD_5 to total BOD_5 equal to 0.8 for all units.

TABLE II-12

SAND FILTER EFFLUENT CHARACTERISTICS (mg/L)
(Siegrist, 1978)

	GREY WATER				GREY/BLACK WATER			
	FILTER NUMBER							
Parameter	1	2	3	4	5	6	7	8
BOD_5[a]	1	1	1	1	2	1	4	4
COD	26	17	21	16	16	18	25	57
S. S[a]	12	14	11	8	8	15	18	17
USS	8	7	7	5	5	6	10	8

a Log-Normalized data.

nitrogen present in septic tank effluents, but left the phosphorus largely unchanged.

Bennett and Linstedt (1975) designed a bench scale treatment unit to evaluate the efficiency of biological oxidation, sedimentation, filtration and carbon adsorption in treating soap related wastewater for a home treatment system. The treatment alternatives are shown in Table II-13.

Biological treatment in the pilot treatment unit consisted of an aeration reactor and a settling tank. Two dual-media, sand-coal filters, were installed to evaluate the removal of solids by in-depth filtration. The filters, 5.1 cm in diameter plexiglass columns contained a 27.9 cm deep layer of approximately 0.5 mm diameter silica sand. A volume of 37.85 L of wastewater passed through the filter beds every day over a span of four hours.

Two columns 1.5 m in length and 6.4 cm in diameter containing 1.1 m of washed virgin activated carbon were installed similar to the filter columns, 37.85 L of wastewater passed through the columns daily over a four hour time span, giving a contact time of 20 minutes in each carbon bed.

The authors found that when the influent that had received no previous treatment was passed through the filter column COD was reduced by 39.4%, BOD_5 by 45.9%, total solids by 11.7%, dissolved solids by 4.4% and turbidity by 41.3%. The treatment of other parameters is shown in table II-14. Dual-media filtration of an influent that had previously

TABLE II-13

Treatment Alternatives

(Bennett et al., 1975)

1. Aerobic (biological) and sedimentation
   a. No pretreatment
2. Filtration
   a. without pretreatment
   b. with pretreatment
      1) aerobic(biological) and sedimentation
3. Carbon adsorption
   a. without pretreatment
   b. with pretreatment
      1) aerobic(biological) and sedimentation
      2) filtration
      3) aerobic(biological), sedimentation and filtration

TABLE II-14

POLLUTION REDUCTION
TYPE OF TREATMENT: DUAL MEDIA FILTRATION
WITHOUT PRETREATMENT
(Bennett et al, 1975)

Parameter	Influent	SAMPLE POINT 11" of Anthracite Coal	Dual Media Filter Effluent
COD (mg/L)	213	143	129
BOD (mg/L)	85	50	46
TS (mg/L)	299	249	264
TFS (mg/L)	183	173	176
TVS (mg/L)	116	76	88
DS (mg/L)	206	189	197
FDS (mg/L)	151	139	137
VDS (mg/L)	55	50	60
Total-PO_4 (mg/L) as P	10.2	9.0	11.0
Ortho-PO_4 (mg/L) as P	3.0	2.8	2.0
NH_3-N (mg/L)	0	0	0
Organic-N (mg/L)	1.3	1.3	1.3
Turbidity (JTU)	46	26	27
Coliforms (#/100 mL)	1.5×10^6	-	1.5×10^6

been passed through biological treatment and subsequent sedimentation was not effective in removing the remaining pollutants present. The quality of the influent and the effluent were nearly identical with the exception of turbidity and organic nitrogen. The reason for this behaviour could be that pollution in the influent was primarily dissolved since it had been treated in aeration and sedimentation reactors. Therefore, the pollutants were not susceptible to capture in a dual-media filter.

In both kinds of filter treatment, coliforms were not removed indicating the need for disinfection or other alternate treatment method.

Four degrees of pretreatment were used when utilizing carbon adsorption columns. They are as follows:

1. No previous treatment
2. Dual-media filtration
3. Extended aeration and sedimentation
4. Extended aeration, sedimentation, and dual-media filtration

The most efficient system was found to be aeration-sedimentation followed by carbon adsorption. The high quality effluent from the aeration unit when further treated with carbon resulted in an effluent with a BOD_5 of 6 mg/L, suspended solids of 22 mg/L and turbidity of 6.1 JTU. Bennett and Linstedt (1975) suggested that this effluent, after disinfection, would be acceptable for many reuse purposes.

They concluded that plain aeration treatment with a 4 day detention time was an effective method for stabilizing the BOD_5 of soap related wastes.

Disinfection

Disinfection is the process of destroying the majority of microorganisms in or on a substance with the probability that all pathogenic bacteria are destroyed, that is, selective destruction of disease-causing organisms. In the field of wastewater treatment, the two catergories of human enteric organisms of the greatest consequence in producing diseases are bacteria and viruses.

Disinfection is most commonly accomplished by the use of either chemical agents or physical agents. Chemical agents that can be used include chlorine and its compounds, bromine, iodine, ozone and lime. Physical disinfectants that can be used are heat and light (UV radiation).

Heat is not a feasible means of disinfecting large quantities of wastewater because of the high energy cost. The efficiency of UV radiation depends on the penetration of the rays into water. Microorganisms, as well as suspended matter, dissolved organic molecules and water will absorb the radiation.

At present, the most common method of disinfecting wastewater is by the addition of chlorine. However, some of the adverse effects that may be caused by the addition of chlorine, including the possible formation of carcinogenic compounds, are only now becoming appreciated, and a variety

of other means for achieving the disinfection of wastewater are currently under investigation.

The most common chlorine compounds used in wastewater treatment plants are chlorine gas, calcium hypochlorite, sodium hypochlorite and chlorine dioxide.

When chlorine gas is dissolved in water, it hydrolizes rapidly, forming hypochlorous acid (HOCl), which can further ionize to form hypochlorite ion (OCl^-) and hydrogen ion (H^+). The amount of each chlorine species present at any time is somewhat dependent on ionic strength and temperature, but is primarily dependent on pH. At pH 6.0, more than 95% of free chlorine exists as HOCl, while at pH 10, over 95% is OCl^-. The relative distribution of HOCL and OCL^- in water is very important because the killing efficiency of HOCL is about 40 to 80 times that of OCL^-. The quantity of HOCL and OCL^- that is present in water is called free available chlorine. The application of hypochlorites to water results in a similar distribution of hypochlorus acid and hypochlorite ion. In wastewater, the free chlorine species combine with ammonia to form chloramines in the successive reactions:

$$HOCl + NH_3 = NH_2Cl + H_2O \quad (1)$$

$$NH_2Cl + HOCl = NHCl_2 + H_2O \quad ---(2)$$

$$NHCl_2 + HOCl = NCl_3 + H_2O \quad ---(3)$$

These reactions are extremely rapid and will occur preferentially to disinfection because hypochlorous acid is very active oxidizing agent. The reactions are very

dependent on the pH, temperature, contact time and on the initial ratio of chlorine to ammonia (White, 1972). At pH 6, dichloramines ($NHCl_2$) predominate while at pH 10, almost all of the chlorine will exist as monochloramines (NH_2Cl). The chlorine in the two predorinant species, NH_2CL and $NHCl_2$, is called combined available chlorine. These chloramines also serve as disinfectants although they are extremely slow-reacting.

Once all the ammonia present has reacted with chlorine, further addition of chlorine leads to the conversion of some chloramines to nitrogen trichloride, oxidation of chloramines to nitrous oxide(N_2O) and nitrogen(N_2), reduction of chlorine to chloride ion, may occur according to following reactions:

$$NH_2Cl + NHCl_2 + HOCl = N_2O + 4HCl \quad ---(4)$$

$$4NH_2Cl + 3Cl_2 + H_2O = N_2 + N_2O + 10HCl \quad ---(5)$$

$$2NH_2Cl + HOCl = N_2 + H_2O + 3HCl \quad ---(6)$$

$$NH_2CL + NHCl_2 = N_2 + 3HCl \quad ---(7)$$

After most chloramines have been oxidized, additional chlorine added to water produces free chlorine residuals ($HOCl$, OCl^-). Chlorination of water to the extent that all ammonia is converted to nitrogen trichloride or oxidized to free nitrogen or other gases is referred to as "breakpoint chlorination ".

The main reason for adding enough chlorine to obtain a free chlorine residual is that usually disinfection is thereby assured. However, chlorination beyond the breakpoint

to obtain free hypochlorous acid is not economically feasible in many situations. In such cases, the contact time becomes important since HOCl and monochloramine are equally effective as disinfecting compounds, only the contact time required is different (Metcalf and Eddy, 1979).

Dichloramine is a more potent germicide than monochloramine. At pH 4.5 and with 0.5 ppm chloramine (probably 100% dichloramine) disinfection was achieved in 20 minutes, whereas at pH 8.6 (probably 100% monochloramine) it required 60 minutes (White, 1972).

The relative germicidal value of the three chlorine residuals (HOCl, OCL^- and monochloramine) has been summarized for E.coli by Clarke et al. (1964). At a 0.1 mg/L residual chlorine, to give a 99% reduction of E.coli, a 66 fold increase in contact time with OCl^- ion and a 300 fold increase in time with monochloramine is required compared to contact time with HOCl.

Bennett and Linstedt (1975) found essentially negligible coliform count(<11/100 mL) using in one case diluted laundry bleach (NaOCl) and an air lift feeder and in the second approach using chlorine tablet feeder which introduced calcium hypochlorite tablets or chlorinated isocyanurates into the storage tank.

As domestic wastewater will likely contain ammonia or organic nitrogen as TKN, the prime disinfectant will be monochloramine if breakpoint chlorination is not used. Collins et al. (1970) indicate that a 32 minute contact time

would be necessary for a 99% reduction of coliforms. White (1974) investigated disinfection practice at 26 California treatment plants during a 6 month period in 1972. His data indicated that disinfection of both primary and secondary plant effluents was capable fo achieving extremely low bacterial counts (approx. 10/100 mL). However, optimum residuals were 3-4 mg/L after a contact time for an initial chlorine demand of less than 15 mg/L. He suggested that initial mixing was of major importance particularly if chlorine demand is high.

Johnson et al. (1978) found that adequate disinfection was obtained with combined chlorine residual within a contact period of 60 minutes or less for primary and secondary as well as filtered and unfiltered lagoon effluents. Combined chlorine residuals of between 0.5 and 1.0 mg/L were found to be adequate in reducing fecal coliform below the discharge standard of 200/100 mL. This residual was produced by a chlorine dose of between 2-3 mg/L for waste stabilization lagoon effluent. Filtering of lagoon effluent through intermittent sand filters prior to chlorination was found to reduce chlorine demand and enhance disinfection efficiency.

According to the U.S. Environmental Protection Agency task force report (EPA,1976) enteroviruses, such as polio and coxsackie viruses, appear to be more resistant, in general, than bacteria to chlorine. Clark et al. (1964) indicated that a 4 fold increase in contact time for

Poliovirus type 1 and a 20 fold increase in contact time for Coxsackie A2 was required, relative to E.coli, to obtain a 99% kill.

Unfortunately, definitive data on viricidal efficiency of the chlorination process is not available at present. It appears that chlorination beyond the breakpoint to obtain free chlorine will be required to kill many of the viruses of concern. However, many of the organic compounds found in wastewater react with chlorine to form toxic compounds that can have long-term adverse effects. Several investigators (Esvelt et al. 1973; Merkens, 1958; Zillich, 1972; Arthur and Eaton, 1971; Brungs, 1973) have found acute toxic effects of chlorine residuals to test fish.

Although no direct evidence is available of any human health hazards from halogenated hydrocarbons, a statistical relationship appears to have been observed between the presence of certain chlorinated hydrocarbons (chloroform, for example) and a slightly larger incidence of some types of cancer in humans (Alavanja et al., 1977).

To minimize the effects of potentially toxic chlorine residuals on the environment, it has been found necessary to dechlorinate wastewater treated with chlorine. Dechlorination is the practice of removing the total combined chlorine residual that exists after chlorination. Sulfur dioxide, activated carbon, sodium sulfite and sodium metabisulfite have been used as dechlorinating agents. Snoeyink and Suidan (1975) found SO_2 to be the most suitable

dechlorinating agent because the same type of feed equipment can be used as is used for the dosing of chlorine. Gan et al. (1978) also concluded that SO_2 is the most preferred method for dechlorination of wastewater in California, and is a more cost-effective process than activated carbon. However, they found bacteriological aftergrowth in some microorganism populations after dechlorination. Regrowth is defined as the increase in numbers of viable bacteria following their reduction by a bactericidal substance. Regrowth was observed predominantly for total coliforms. There was some increase in fecal coliforms but fecal streptococci in the effluent remained relatively unchanged after dechlorination, suggesting a different potential for regrowth for different groups of organisms.

Regrowth has also been found to occur in chlorinated effluents. Regrowth of both fecal and total coliforms was observed by Shuval et al. (1973) in a well treated wastewater after 50 hours. Fecal coliforms did not generally show regrowth to the same extent as coliforms. There appeared to be an inverse relationship between the occurrence of regrowth in the holding tank and (1) the residual chlorine in the tank and (2) the number of bacteria surviving chlorination. The latter relationship may be due to the general absence of competitive microflora and/or to the fact that the wastewater effluent provides sufficient nutrients to allow for the regrowth and maintenance of a certain level of coliforms. When the coliform counts are

reduced to below that level they may be able to regrow, but when the coliform count after chlorination remains higher than that level, there are insufficient nutrients to allow for further growth.

Deaner and Kerri (1969) were unable to detect regrowth of fecal coliform in river water receiving sewage treatment plant effluent. They attribute this absence of regrowth to a low level of nutrients in the receiving water and the short time interval of testing for regrowth , that is 5 hours after discharge.

Studies have demonstrated different capacities of regrowth for different groups of coliforms. Therefore, one cannot assume that when coliforms regrow, the pathogens are regrowing as well. Some studies have been conducted regarding regrowth phenomenon of pathogens, although such has not been demonstrated conclusively.

Wastewater disinfection in the cold northern regions of Canada presents some difficult problems. The chemical reaction rate of chlorine with wastewater constituents decreases with decreasing temperatures. Consequently, the speed with which disinfection proceeds is also reduced. Further, the survival time of sewage bacteria in the cold streams and rivers has been found to be longer than in the warmer southern waters (Gordon, 1972). For these reasons chlorine contact time may have to be longer than normally employed in the warmer zones. As an additional precaution a chlorine residual of 1 mg/L is maintained in Alaska (Gorur,

1975) which is higher than the normal values.

Roberts and Vajdic (1974) found chlorine dioxide to be a superior disinfectant to chlorine. Bactericidal efficiency of chlorine dioxide was comparable to that of chlorine in the neutral pH range, but increased significantly with pH. Thus, chlorine dioxide is possibly a more effective disinfectant for the treatment of sewage effluents.

Moffa et al. (1975) reported reduction of total coliform, fecal coliform and fecal streptococci to 1000, 200 and 200 colonies per 100 mL, respectively, by 2 minutes contact at disinfectant dosages of 25 mg/L chlorine or 12 mg/L chlorine dioxide. They also found five log reductions in two test virus types.

However, chlorine dioxide is more irritable, more toxic and more expensive than chlorine and highly unstable in both the gaseous and liquid form. It is highly explosive at a slight change in temperature or when exposed to light. Therefore, it is normally produced on site. In aqueous solution chlorine dioxide is harmless. The advantages of chlorine dioxide are that it does not react with ammonia nor does it dissociate in water.

Another alternative to chlorine, that has been examined for wastewater disinfection is bromine. The major advantage of bromine is that bromamines are better disinfectants and less stable than chloramines. The bromamines are reported to break down into harmless elements in less than an hour (Gorur, 1975). Sollo et al. (1975) compared the use of

chlorine and bromine at pH values of 6.0, 7.5 and 9.0. They observed that although the two halogens performed similarly at pH 7.5, chlorine was three times as effective at pH 6.0 and bromine was three times as effective at pH 9.0. This is due to the relative disinfecting capabilities of chloramines and bromamines. At lower pH relatively unstable dibromamine is formed and at higher pH values the more stable monobromamine is formed. Chlorine is less effective at high pH due to the formation of OCl^- which is a much weaker disinfectant than HOCl.

Johnson and Sun (1975) found similar results when comparing the efficiencies of bromine and chlorine in the destruction of coliform organisms in an alum coagulated trickling filter effluent.

Cramer et al. (1976) examined the performance of chlorine and iodine on poliovirus III and F2 bacterial virus. They found iodine to be superior to chlorine at higher pH values. However, iodine is much more expensive than chlorine and higher concentrations are required to produce a comparable bacterial kill. An advantage of using iodine as a disinfectant is that it does not react with ammonia.

One of the most promising chemical disinfectant that has recently received a great deal of attention is ozone, especially for disinfecting dilute, low-temperature wastewater. Ozone does not form toxic compounds in wastewater. However, because of the unstable nature of ozone

it cannot be stored and transported and consequently on-site generation is necessary.

Diaper (1975) examined the performance of ozone using two ozone contact columns and venturi injectors for mixing the secondary effluent with the ozone. He found that at a ozone dose of about 6 mg/L substantial reductions in total coliform and fecal coliform occurred.

Singer and Zilli (1975) examined the ozonation of ammonia in wastewater and found that if the wastewater can be maintained alkaline (pH 7 to 9) the process is effective.

In another study, Wynn et al. (1973) examined tertiary treatment of wastewater with ozone in a nominal 190 m^3/d pilot plant. The Most Probable Numbers for standard plate count, total coliform and E.coli were reduced to the detection limit when pretreated wastewater was disinfected with ozone.

Three recent studies (Cairns et al., 1977; Guirguis et al., 1975; Ward et al., 1977) reported difficulties with ozone wastewater treatment systems. Guirguis et al. (1975) found the application of ozone impractical at the Cleveland Westerly Wastewater Treatment Plant due to several operating conditions such as wide variation in influent parameters, non-domestic organic and inorganic material coming through the pilot plant and the need to vary the dosage frequently to maintain optimum performance. The report by Ward et al. (1977) noted that the disinfection capability of ozone was often limited by an inadequate dosage resulting from design

limitations, mechanical failures and operator inexperience.

Nebel et al. (1976) suggested the ranges of dosages for wastewater treatment, presented in Table II-15. Nebel et al. (1973) reported that a concentration of 0.1 mg/L of ozone required 0.8 minutes to achieve 99.9% reduction in bacteria compared to 250 minutes for the same concentration of chlorine. They also showed that coliforms and pathogens are reduced to levels below the legal requirements by ozone dosages of 5-8 mg/L for secondary municipal effluents.

Kinman (1974) examined ozone disinfection of dilute wastewater and found that for 10 and 20% wastewater dilutions and ozone concentrations between 2.10 and 3.49 mg/L, total bacteria were reduced by 99.6% and total coliform were reduced by 99.7% in one minute.

Ross et al. (1975) used Pseudomonas aeruginosa to compare chlorine and ozone as disinfectants. They found ozone to be much more efficient in water with a chlorine demand such as ammonia.

Several studies have been conducted on the ability of ozone to inactivate viruses. Majumdar et al. (1974) reported on the inactivation of poliovirus by ozone in distilled water and pretreated secondary effluent at a concentration of 1 mg/L ozone.

Katzenelson and Biedermann (1976) examined the destruction of poliovirus 1 in a filtered and frozen secondary effluent. At an ozone residual of 0.6 to 1.0 mg/L an inactivation of more than 99.9% was achieved.

TABLE II-15

(Nebel *et al*, 1976)

Type of Waste Water	Ozone Dosage mg/L
Primary Sewage & Storm Water	10 - 100
Secondary Treatment for Potable Water	50
Disinfection of Secondary Effluent	5 - 15

+ + + + + + + + + + + +

Pavoni et al. (1974) found 100% efficiency for inactivation of F2 virus after 5 minutes contact time with an ozone residual of 0.015 mg/L. In contrast, a chlorine residual of 9 mg/L with 15 minutes contact time was necessary for 90% removal.

The cost of ozone treatment is one of the factors limiting its use. Rosen et al. (1975) reported the energy requirments for ozone production as 3.63 kwh per kg of ozone using air plus 1.59 kwh per kg of ozone for air compression and drying. Besides the generation of ozone, energy is required for mixing ozone in the wastewater. Another factor limiting the use of ozone is the potential toxic effects to the operating personnel. Ozone is known to be a toxic gas.

Morrison et al. (1973) examined the use of lime as a disinfectant. They reported that even in high concentrations of organic matter and low temperature conditions, wastes could be disinfected by lime treatment to pH 11.5 or 12.0 with 30 minutes contact time. They suggested average dosage of lime from 250 to 435 mg/L for raw sewage and 430 to 1000 mg/L for secondary effluents. However, treatment at pH values at or below 11.0 failed to adequately disinfect effluents within a reasonable time period at any of the treatment temperatures studied (1-15^{0}C). The problems related with lime treatment are the amount of sludge produced and related handling problems and also the requirement of pH adjustment of the wastewater before discharge.

Similar results were reported by Brouzes et al. (1974). At pH 11.5 the total coliform counts reduction in the treatment were approximately 99.998%. The fecal streptococci were more resistant showing a reduction of 98%. Poliovirus type 1 virus showed a 99.998% reduction after one hour and at the end of 48 hours a total and complete inactivation of the virus was observed. However, the final effluent after lime treatment was toxic to fish. Reduction in toxicity was noted after pH adjustment to neutrality and air stripping to remove high CO_2 levels.

Since the process of lime treatment is not dependent on temperature, it seems to be particularly suited to conditions in northern Canada where severely cold climatic conditions prevail during the major part of the year (Gorur,1975). However, there are associated problems of transportation and storing of the needed chemicals and also final disposal of lime sludge.

Another technique for disinfection is by physical action on the cell. These include the application of ultraviolet light, heat, ultrasonic vibration and radiation. The disinfection of wastewater with UV light is the most promising. It is a simple process to operate, with most bacteria being deactivated in seconds and there is no danger of overdose. One major drawback to UV irradiation is high initial capital investment. The advantage of UV radiation is that it does not change the wastewater characteristics as do chemical disinfectants (Gorur, 1975).

Yip and Konasewich (1972) found that all the pathogens or viruses investigated were as sensitive or more sensitive to UV light than were fecal coliforms.

Initial studies with UV irradiation of sand-filtered household effluents have been conducted at University of Wisconsin (EPA, 1977). The results from 4 months of operation with a commercial UV unit are shown in table II-16.

Realizing that the chemical characteristics of combined wastewater are not the same as greywater, the above literature review does present a reference base for choosing a treatment system for household wastewater.

TABLE II-16

COLIFORM ANALYSIS OF EFFLUENTS FROM SAND FILTER AND ULTRAVIOLET UNITS (U.S. E.P.A., 1977)

Coliforms	Aerobic Units		Septic Tank	
	Sand Filter	UV	Sand Filter	UV
Fecal Coliforms	11 to 13/100 mL	1/100 mL	$(2.6\text{-}4.4) \times 10^3$ per 100 mL	1/100 mL
Total Coliforms	64 to 75/100 mL	1/100 mL	$(3.6\text{-}5.1) \times 10^3$ per 100 mL	1/100 mL

+ + + + + + + + + + + + + +

III. GREYWATER PRODUCTION AND MANAGEMENT IN THE NORTH

At present, the methods of wastewater collection and disposal used in most northern communities are basically of two types, holding tank or honey bags which are trucked to either sewage lagoons or dumps. Lack of funds for conventional water and gravity sewer systems, and harsh climatic conditions, will necessitate the continued use of trucked systems for many years, particularly in the smaller settlements in permafrost regions.

Many communities in the N.W.T. rely on bucket toilets. Their contents in plastic bags ('honey-bags') are picked up several times a week and trucked to dumps, or sludge pits. Some homes in larger communities use water flush toilets which are connected to a storage tank in the home the contents of which are pumped out once a week to a tank-truck. Normally, other household liquid wastes from kitchen sinks, bathtubs, and laundry are also connected to the holding tank. Therefore, sewage from holding tanks is more dilute than contents of 'honey-bags'. In most cases, the holding tank waste is disposed of directly to land. From an environmental and public health standpoint such a method is undesirable.

With the exception of a few larger communities, most do not practice sewage treatment. Those that do generally use lagoons. However, there are inherent drawbacks to this method of treatment. In areas of permafrost, lagooning is complicated by the presence of ice wedges, or high ice

content soil. Also, bodies of surface water create an appreciable perturbation in the ground thermal regime in permafrost areas, leading to structural and seepage problems for the containing embankments. The town of Baker Lake in the Keewatin district has been experiencing such problems with the lagoon system.

Larger towns in the N.W.T. are now benefiting from the advantages of piped water and indoor flush toilets. However, the system cannot be buried in many areas for they would either freeze up or collapse if their heat melted the permafrost. The solution for this problem has been the use of utilidors which are weatherproof box structures containing the piping within an insulated interior, that are installed above ground on pilings, berms or logs. Most systems have recirculating heat lines to keep the water and sewer line from freezing. Inuvik has such a system which empties the wastewater into a lagoon for treatment. However, this is an expensive system especially for a small settlement where houses are quite spread out. This system of multiple pipes in a box above ground is now being replaced by individually insulated shallow buried water and sewer pipes in permafrost regions. Above ground systems are exposed to extremes of temperatures, as well as accidental damage, vandalism and present physical barriers that are functionally and aesthetically undesirable. Shallow buried pipe systems have or are being installed in Norman Wells, Resolute, Frobisher, Rankin Inlet and Ft. Rae.

As shown in table III-1 out of approximately 60 communities in N.W.T. only 11 have piped sewerage systems, out of which Six communities also have holding tank and/or honey bags. Eleven communities use holding tanks for sewage and the rest rely on honey bags. Sewage is disposed of on land at a dump by approximately 24 communities. Nine communities dispose of sewage to lagoons.

In most settlements using 'honey-bags' for toilet wastes, kitchen and laundry wastewater is disposed of by pipe directly onto the ground surrounding the house (Plate III-1). With proper drainage and ground conditions this system might be adequate. However, most northern communities lack suitable soil conditions. Most settlements experience drainage problems and ponding is not uncommon in these areas (Plate III-2). Large ponds provide a breeding ground for mosquitoes and blackflies. Flies are known to be mechanical vectors for transmitting the disease shigellosis. Since greywater may contain a large indicator population, suggesting the possible presence of pathogens, ponding of greywater can be a public health hazard. Some public health officials feel that this greywater contributes to the occurrence of diseases, particularly in children. As mentioned previously, infectious hepatitis, shigellosis, gastroenteritis, salmonellosis , streptococcal sore throats and tuberculosis have been commonly reported in communities in the N.W.T. Table II-1 showed the number of cases of each disease reported by the nurses in each community during the

Water Supply & Wastewater System in Northwest Territories

Water Supply — Table III - 1 (Wood, 1977) — Sewerage

Community	Population	Source	Treatment	Piped all year	Piped summer (water points)	Trucked homes	Waterpoints	Trucked ice	Individual	Disposal	Piped	Truck (holding tanks)	Truck (honey bag)	Individual
Aklavik	700	Lake & Peel River	Cl_2		+	+	+			Dump		+	+	
Arctic Bay	353	Lake			+		+	+		Dump			+	
Arctic Red River	135	Lake or Mackenzie R.					+		+	Dump			+	+
Baker Lake	900	Lake		+		+	+			Dump		+	+	
Broughton	395	River					+	+		Bay			+	+
Cambridge Bay	856	Lake	Cl_2			+				Bay		+	+	
Cape Dorset	664	Lake			+		+	+		Bay			+	
Chesterfield Inlet	254	Lake				+	+		+	Bay			+	
Clyde	363	Lake				+				Dump			+	
Colville Lake	76	Lake							+					+
Coppermine	756	River	Cl_2			+			+	Bay			+	+
Coral Harbour	425	Lake			+	+	+	+		Bay			+	
Detah	159	Yellowknife Bay				+							+	
Discovery	275	Lake		+										

Water Supply & Wastewater System in Northwest Territories

Table III - 1 (Wood, 1977)

Community	Population	Water Supply: Source	Water Supply: Treatment	Water Supply: Piped all year	Water Supply: Piped summer (water points)	Water Supply: Trucked homes	Water Supply: Waterpoints	Water Supply: Trucked ice	Water Supply: Individual	Sewerage: Disposal	Sewerage: Piped	Sewerage: Truck (holding tanks)	Sewerage: Truck (honey bag)	Sewerage: Individual
Eskimo Point	675	Lake			+	+				Dump			+	
Ft. Franklin	410	Lake	Cl_2			+	+		+	Lagoon & Dump		+	+	
Port Good Hope	376	Lake & River	Cl_2			+	+		+				+	+
Fort Liard	253	Wells					+						+	+
Ft. McPherson	789	Lake		+		+			+	Lagoon & Dump	+		+	
Ft. Norman	279	River				+	+		+				+	+
Port Providence	607	River				+				Dump		+		
Fort Resolution	736	Lake				+			+	Dump			+	+
Ft. Simpson	1050	River		+			+			River & Dump	+	+	+	
Fort Smith	2810	River	Cl_2 F	+						Lagoon	+			
Frobisher Bay	2418	Lake	Plant	+		+				Bay	+	+	+	
Gjoa Haven	402	River & Lake				+	+	+	+	Bay			+	+
Grise Fiord	129	stream					+	+	+	Dump & Bay			+	+

Water Supply & Wastewater System in Northwest Territories

Water Supply

Table III - 1 (Wood, 1977)

Community	Population	Source	Water Supply: Treatment	Piped all year	Piped summer (water points)	Trucked homes	Waterpoints	Trucked ice	Individual	Sewerage: Disposal	Piped	Truck (holding tanks)	Truck (honey bag)	Individual
Hall Beach	312	Lake			+	+		+		Dump			+	
Hay River	4018	Lake	Cl_2 P	+		+				Lagoon	+			
Holman	288	Pond				+				Dump & Bay			+	
Igloolik	645	Lake				+				Dump			+	
Inuvik	3100	River & Lake		+		+				Lagoon & Dump	+		+	
Jean Marie River	56	Wells and River							+	Dump				+
Kalasa Lake	40								+					+
Lac le Martre	191					+								+
Lala Harbour	224	Pond				+				Dump & Bay			+	
Nahanni Butte	79	River & Wells							+	Privy				+
Nanisivile	265			+							+			
Norman Wells	353	River	Plant	+		+				Septic Tank & Lagoon	+	+		

Water Supply & Wastewater System in Northwest Territories

Water Supply
Table III - 1 (Wood, 1977)

Community	Population	Source	Water Supply: Treatment	Piped all year	Piped summer (water points)	Trucked homes	Waterpoints	Trucked ice	Individual	Sewerage: Disposal	Piped	Truck (holding tanks)	Truck (honey bag)	Individual
Panguirtung	906	River			+	+				Bay & Dump			+	
Pelly Bay	255	Lake				+			+	Dump			+	+
Pine Point	1451	Wells	Plant	+						Lagoon	+			
Pond Inlet	493	Lake				+				Dump			+	
Rae Edzo	1319	Lake	Cl_2	+		+				Lagoon		+	+	
Rankin Inlet	840	Lake		+		+	+			Septic Tank & Dump	+		+	
Repulse Bay	274	Lake				+				Bay & Dump			+	
Resolute	556	Lake				+	+						+	
Sachs Harbour	168	Stream, Lake, ice				+		+		Bay			+	
Sanikiluaq	304					+							+	
Snowdrift	253	Lake				+			+	Privy			+	+
Spence Bay	433	Lake				+				Bay			+	
Trout Lake	57	Well							+	Privy				+
Tuktoyaktuk	697	Lake & Sea	Cl_2			+	+			Dump		+	+	

Water Supply & Wastewater System in Northwest Territories

Water Supply
Table III - 1 (Wood, 1977)

Community	Population	Source	Treatment	Piped all year	Piped summer (water points)	Trucked homes	Waterpoints	Trucked ice	Individual	Sewerage: Disposal	Piped	Truck (holding tanks)	Truck (Honey bag)	Individual
Tungsten	295	River	Cl_2 F	+						Septic Tank		+		
Whale Cove	171	Lake				+				Dump			+	
Wrigley	212	River				+				Privy				+
Yellowknife	9950	Lake		+						Lagoon	+			

Waste water pipe at the side of a house
in Whale Cove

Plate III-I

Poor drainage near homes

Plate III-2

period 1974 to 1978. Though no concrete evidence exists as to the mode of transmission of the above diseases, greywater can be regarded as a possible mode of transmission for two reasons. Firstly, before winter freeze-up of greywater, children playing in ponds created by greywater could contact diseases. Secondly, the spring run off of previously frozen greywater can contaminate surface water supplies used for drinking purposes.

Several studies have been reported by Smith (1954) on effects of freezing and thawing on microorganisms. Various experiments have demonstrated conclusively that a wide variety of bacteria and other microorganisms could survive cooling and storage at very low temperatures in the frozen state. However, different species of bacteria vary in their sensitivity to freezing and thawing. Beard (1940) found S.typhosa to survive as long as 24 months at freezing temperatures. Mirzoev (1968) pointed out that in areas with prolonged winters ,e.g., the Russian Arctic, the processes of soil self-disinfection are slowed down or suspended. He showed that low temperatures (down to $-45^{0}C$) were very favorable for the survival of dysentery bacilli, which he was able to detect 135 days after it had been added to the soil.

Thus, if pathogens were to survive freezing and thawing, drinking water for some communities may be contaminated after spring runoff, since most do not practice water treatment. Rather they depend upon the use of a good

quality raw source.

Ft. Franklin is an excellent example of a community experiencing wastewater disposal problem and subsequently drinking water contamination. The topography of the site is such that no matter where sewage is discharged or dumped, it will eventually either directly or through surface drainage pollute the shore of Great Bear Lake around the settlement. Since the lake is the source of water supply, some form of wastewater treatment becomes a necessity. The water supply system at present consists of tank-truck delivery to individual homes. This water may be chlorinated. (Heinke, 1974)

Other communities experience water contamination to a lesser degree, though the possibility of contamination is always present.

A. CASE STUDY: WHALE-COVE

Whale Cove is a small settlement situated on the west coast of Hudson Bay: lat.62°09N, long.92°35W, in the district of Keewatin. The population of the settlement is 179, with a large population of children as of September 1978. All the houses are raised about one and a half feet above the ground by pilings or logs. Most community residents depend on traditional subsistence hunting and fishing for existence. Their diet consists mainly of fish (Arctic Char), caribou and sometimes whale blubber. The latter produces a high grease content in the wastewater from

kitchen sinks. Green vegetables and fruits are not available most of the year.

Water is a scarce commodity in Whale-Cove. It is delivered three times a week by a truck from a small lake 180 m north of the settlement into 170 L plastic tanks at each house (Plate III-3). This lake is deep enough to supply water all year round.

The limited water supply creates a stimulus to reduce water use. Consequently, the pattern of water usage and the volume of wastewater produced differs greatly from the homes in the South. Bathing in each family occurs once a week, dishwashing approximately once a day and laundry about twice a week. Laundering of soiled diapers leads to a source of fecal matter in the greywater produced. Reduction of water use also results in unusually high concentrations of various constituents in the wastewater.

The collection of domestic refuse is probably the most difficult phase of the solid waste problem in the Canadian North and Whale Cove is no exception. Honey-bags and garbage are collected and buried at an area 370 m northeast of the settlement. In winter, they are sometimes dumped on the sea ice.

Domestic refuse is deposited in 170 L drums prior to pick-up. Human wastes, feces and urine, from bucket toilets are collected in plastic bags, i.e. 'honey-bags'. The householder removes the 'honey-bag' from the bucket toilet and places the sealed bag in a 170 L drum(used especially

Water truck filling at lake

Plate III-3

for this purpose) in front of his home from where they are picked-up twice a week by a truck. Sometimes the bags are left on the ground where they are broken by birds, dogs or children and in the winter they freeze to the ground making collection a difficult task. In addition to these toilet wastes, household liquid wastes generated from kitchen, bathroom and laundry are disposed of by pipe to the ground surrounding the house.

Whale Cove, being a very small settlement, has a nursing station with only a single nurse. The station consists of three trailer units joined together, one unit is used as a clinic, one for storage of materials and the third unit is used as nurse's residence. The nurse's living quarters has a 950 L water tank placed in the kitchen, covered up by kitchen counters. Under an insuleted, raised floor in the bathroom is installed a 950 L holding tank for greywater, since here, too a bucket toilet is used. A pipe leading from the holding tank constantly empties the contents onto the surface of ground below the trailer units. Constant emptying of the contents of the tank to the ground is frequently replaced by periodic emptying in the winter to prevent the pipe outlet from becoming blocked by ice. Removal of holding tank wastewater in this manner is unpleasant, inconvenient and difficult.

Sampling of greywater was conducted mainly at the nurse's residence from the holding tank. The retention time of wastewater in the tank ranged from 6 hours to 24 hours.

At the start of the sampling program, plans were made to estimate the volume of wastewater produced from the measurement of volume of water used. However, access to either the holding tank for greywater or to the water tank was not possible and the meter in the water truck was broken. Thus, the amount of water used at the nurse's residence was estimated to be about 1900 L a week since the water tank was filled up approximately twice a week. Other homes in the settlement used 510 L a week for an average family of five. Approximately 15 L water was used for laundry, 8 L in the kitchen, 75 L for bathing and 1 L for hand and face washing.

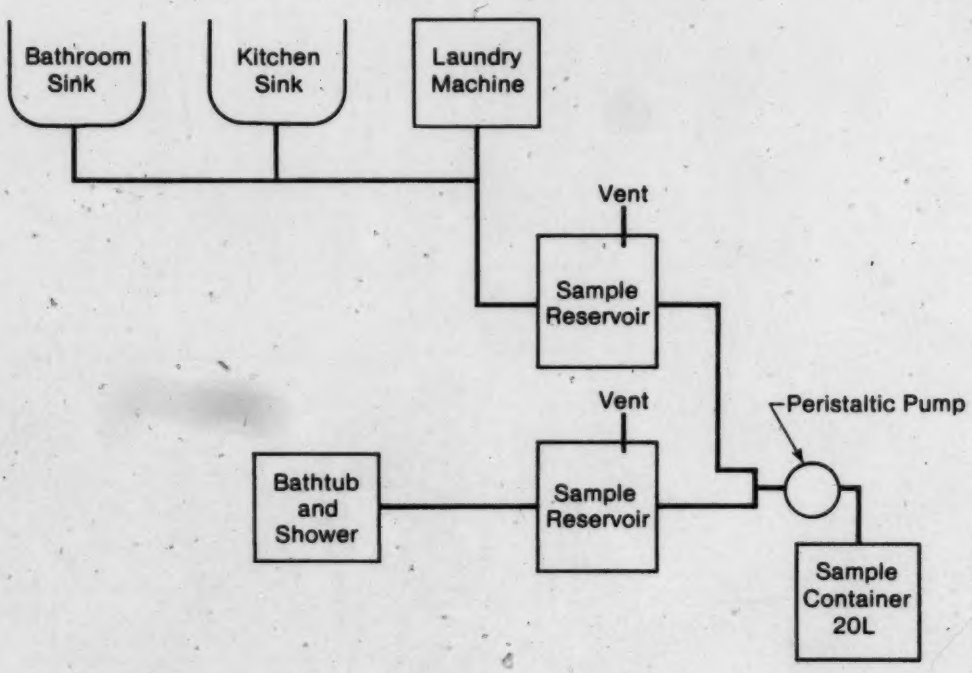
IV. GREYWATER CHARACTERISTICS

In order to study alternatives for the treatment and disposal of individual household wastewaters effectively, the wastewater quantity and quality originating from these homes must be characterized. Wastewater quality studies were conducted at the nurse's residence in Whale Cove, N.W.T. As well, single grab samples were taken from 8 homes in Whale Cove. Holding tank effluent samples were taken from the tank at the nursing station during the period of August 21, 1978 to September 16, 1978. The samples were tested for concentrations of chemical and bacteriological contaminants. In addition, some greywater samples were obtained from a septic tank from a home equipped with a compost toilet in Strathcona County, Alberta and characterized for chemical and bacteriological pollutants. Further samples were obtained from a residence in Edmonton with modified plumbing. These were characterized during the period February 26 - March 29, 1979. The sampling set up for the source in Edmonton is presented in Figure IV-1a and Figure IV-1b.

A. ANALYTICAL METHODS

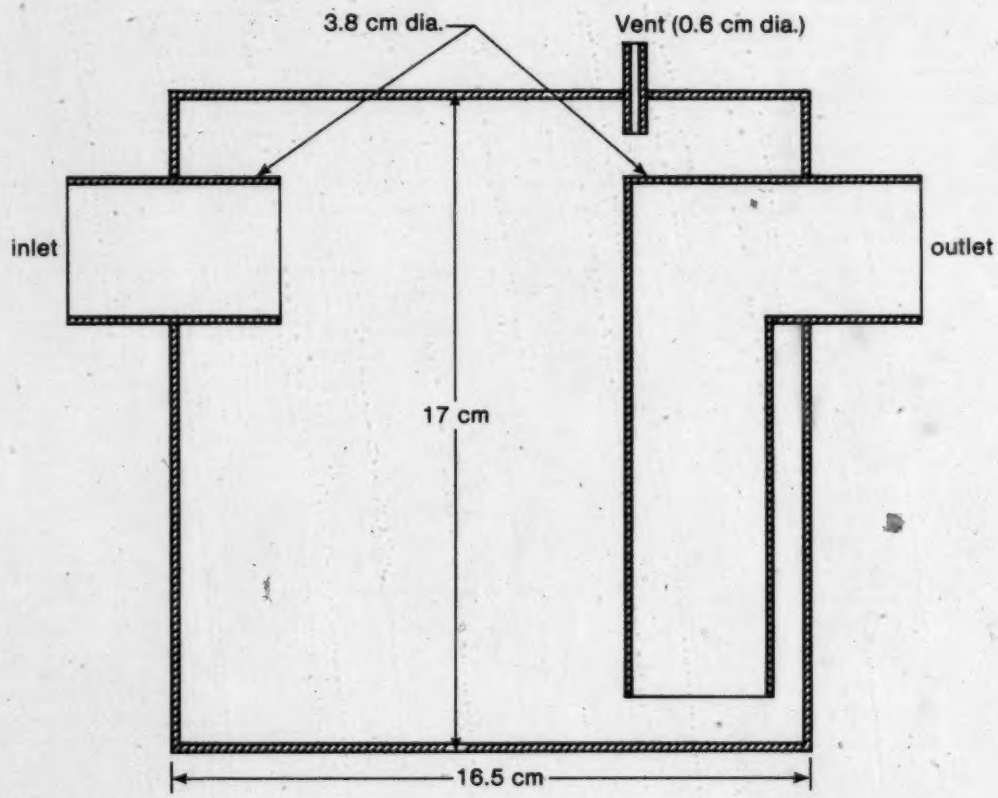
Bacteriological Analysis

Samples were collected on a daily basis and bacteriological analyses were performed on the same day. Each sample was analysed for total coliforms, fecal coliforms and fecal streptococci using the membrane filter



Sampling set-up in Edmonton

Fig. IV-Ia



Sample Reservoir
Fig. IV-Ib

technique. Total coliforms were tested according to procedure outlined in method number 909A (APHA,1975) using commercial LES Endo Agar. This media was prepared by boiling 51 g LES Endo Agar in 1 L distilled water and 20 mL ethanol. About 4 mL quantities were dispensed into pre-sterilized small petri dishes. The standard method number 909C (APHA,1975) was modified for the determination of fecal coliforms. MFC agar media was prepared using 52 g commercial MFC agar in 1 L distilled water containing 10 mL of 1% rosolic acid in 0.2 N sodium hydroxide. Again 4 mL quantities were dispensed to pre-sterilized small petri dishes.

Fecal streptococci were analysed using the membrane filter technique outlined in method number 910B (APHA,1975) except Entrococcus agar media was used rather than KF streptococcus agar media. 42 g commericial entrococcus agar media was boiled in 1 L distilled water and dispensed to small petri dishes. Entrococcus agar media was easier and more convenient to prepare than KF agar media under the primitive and confined "laboratory" conditions available for microbiological work in Whale Cove. Both entrococcus and KF agar media were used for samples from Strathcona County which were analysed in Edmonton. It was found that the temperature at which 1% solution of 2,3,5-triphenyltetrazolium chloride was added to KF agar media had to be carefully kept between 50-60^{0}C. No appreciable difference in numbers of colonies was noted

between the two types of media used for the same sample.

Membrane filter colonies are best counted with a magnification of 10 to 15 diameters either with the use of a binocular wide-field dissecting microscope or a small fluorescent lamp with a magnifier. However, due to the difficulties in transporting expensive instruments to Whale Cove, the colonies were counted with naked eye. A microscope was used for counting colonies of samples obtained from the sources in Strathcona County and in Edmonton.

In addition total bacterial counts were performed using method number 907 (APHA,1975) except that two incubation procedures, one at 35°C for 24 hours and the other at 20°C for 48 hours were used. Since an incubator at 20°C was not available in Whale Cove the samples were set out on a bench top at room temperature which was approximately 18°C.

Total Organic Carbon (TOC)

Samples were preserved with 1 mL/L of concentrated sulphuric acid and stored at 4°C until transported back to Edmonton. Ultrasonic disruption of the acidified sample was adopted before analysis for TOC due to the nature of suspended solids in many of the samples. TOC was determined using a Beckman Model 915 Total Carbon Analyser, method number 505 (APHA,1975). Since the samples were acidified, inorganic carbon was not present and the total carbon channel measured total organic carbon.

Suspended Solids

Suspended solids analyses were performed using 2.1 cm

glass fiber filter disk and membrane filter apparatus according to method number 208D (APHA,1975). The sample size was decreased from 100 mL as suggested in standard methods to 50 mL due to high non-filtrable residue. Suspended solids should be analyzed soon after sample collection. However, since a balance was not available in Whale Cove, samples were preserved with 1 mL/L sulphuric acid and refrigerated at 4^0C, prior to subsequent analysis in Edmonton.

Phosphate Analysis

Since a long holding time for samples was required, the samples were preserved with 40 mg $HgCl_2$ per liter and refrigerated at 0^0C until transported to Edmonton. The following methods were tested for phosphate analysis:

1. Vanamolybdophosphoric acid, method number 425D. (APHA,1975)
2. Ascorbic acid, method number 425F. (APHA,1975)
3. Automated ascorbic acid, method number 606. (APHA,1975)

Vanamolybdophosphoric acid method

Figure IV-2 shows the calibration curve for phosphate between concentrations of 2.5-15 mg/L measured at three different wavelengths. As seen, measurement at wavelength of 470 nm is the most suitable, since a straight line graph is obtained. To test the accuracy of the method, a 50 mL sample of greywater containing 9.0 mg/L PO_4-P was spiked with 0.1219g standard Potassium

Calibration Curve for Phosphorus Determination using
Vanamolybdophosphoric Acid Method

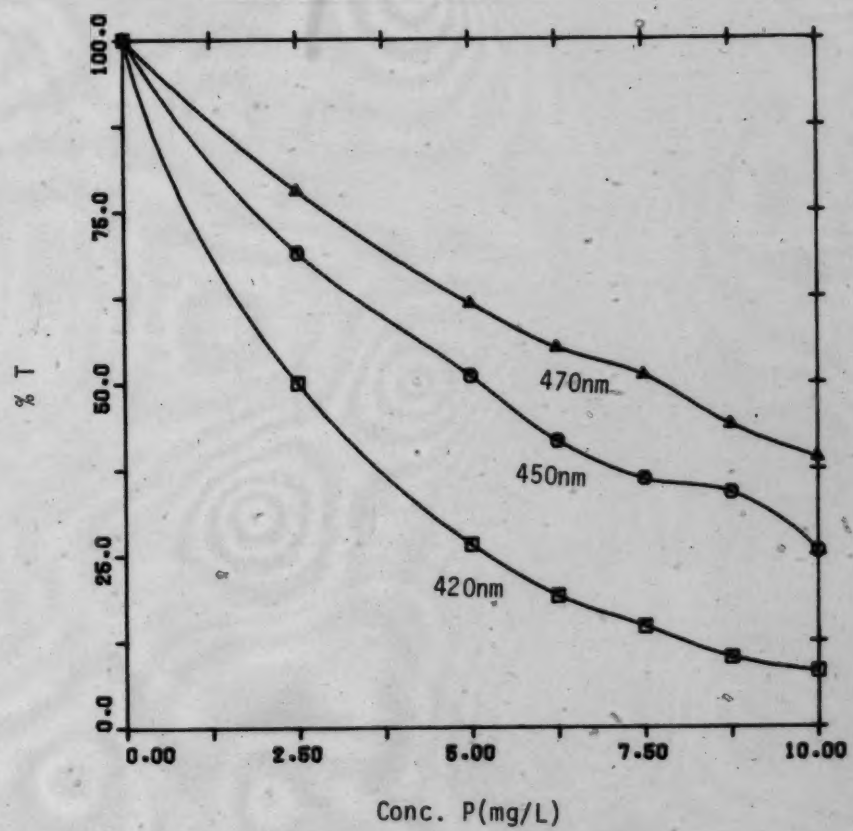


Fig. IV-2

dihydrogen phosphate, i.e. 556 mg/L PO_4-P. The spiked sample was found to contain 525 mg/L PO_4-P giving a recovery of 94%.

To test the effect of preserving the sample, the sample was spiked and preserved for 5 days. Again the 94% PO_4-P was recovered showing preservation of sample had no effect on the analysis.

Since the vanamolybdophosphoric acid method does not detect PO_4-P below 1 mg/L, this method was abandoned.

Ascorbic acid method

The minimum detectable concentration by this method is approximately 10 microgram P/L. Mercury chloride, used as a preservative, interferes when the chloride level of the sample is low (<50 mgCl/L). This interference is overcome by spiking samples with a minimum of 50 mg/L of sodium chloride. (U.S. EPA, 1976) To ascertain this interference two calibration curves were prepared. One set of standards contained 0.1 mL of 5 g/L $HgCl_2$, while the other set of standards was prepared without $HgCl_2$. As shown in Figure IV-3, $HgCl_2$ causes positive interference.

The procedure followed was the one outlined in method 425F (APHA,1975) with the following changes.

The sample volume was reduced to 10 mL from 50 mL

Calibration Curve for Phosphorus Determination using Ascorbic Acid Method

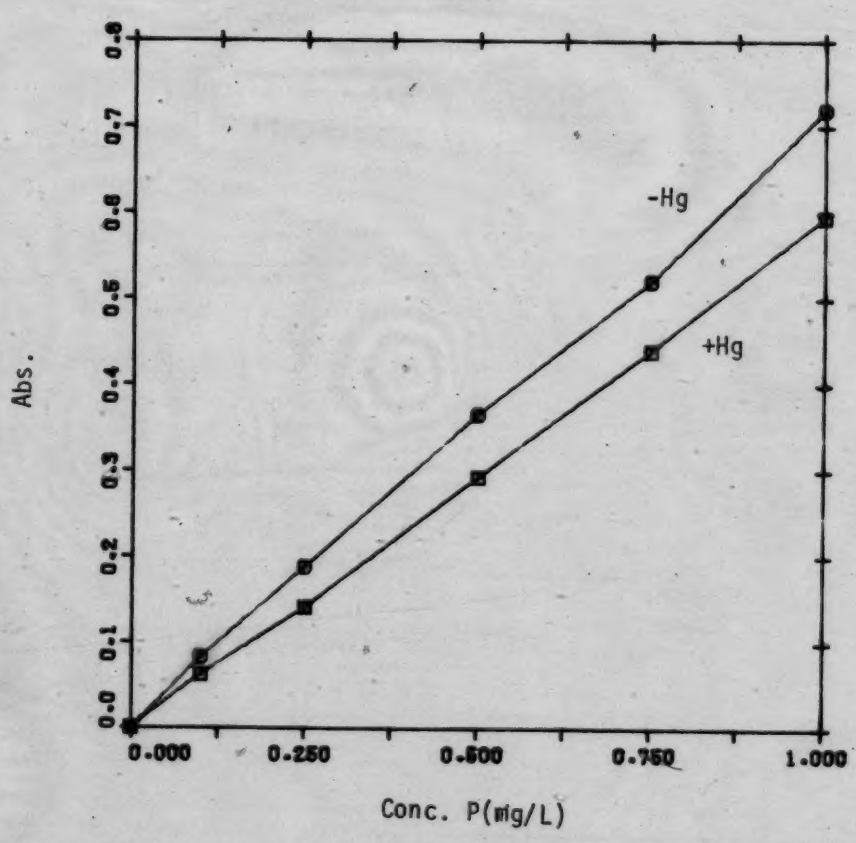


Fig. IV-3

so that 25 mL test-tubes could be used as reaction vessel. This reduction required 1.6 mL mixed reagent. 0.1 mL of 12.5 g/L NaCl solution was added to the 10 mL sample, to overcome the interference.

For the determination of total phosphate, the sample was digested using 0.5 mL 5 N sulphuric acid and 0.2 g ammonium persulfate in a 25 mL sample. The solution was heated in a pressure cooker at 1.03×10^5 Pa for 30 minutes, cooled and neutralized with 1 N NaOH prior to determination of concentration of PO_4-P by the ascorbic acid method.

As shown in Figure IV-4, the recovery of phosphate was low showing that the digestion procedure was not effective. The reason for this behaviour is not known. Since an Ortho-PO_4 standard was used, the PO_4 did not require digestion. It was decided to use a more rigorous digestion procedure. To 25 mL sample 0.1 mL $HgCl_2$, 0.1 mL NaCl, 0.5 mL 11 N H_2SO_4 and 0.2 g ammonium persulphate were added and the sample digested. Figure IV-5 shows a good recovery of PO_4, at the same time showing that the effect of $HgCl_2$ has been eliminated by the addition of NaCl.

However, in a similar test conducted following the test above, turbidity in samples was observed after neutralization but prior to addition of mixed reagent. Elimination of the neutralization step produced the results shown in figure IV-6. Unneutralized samples

Effect of Digestion of Sample on Calibration Curve for Phosphorus

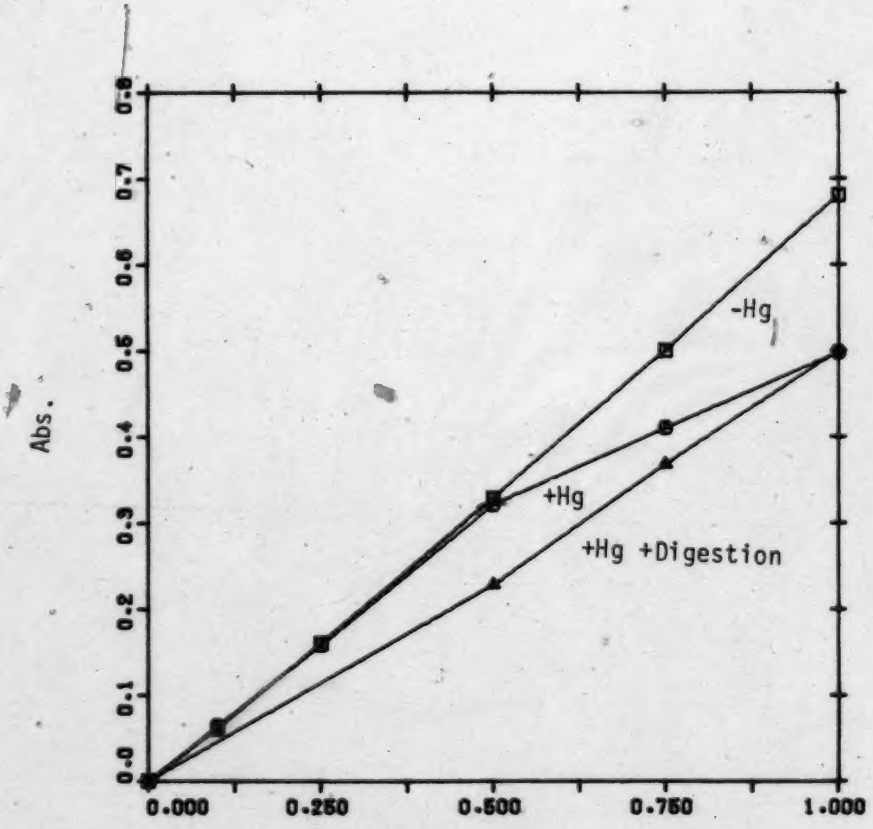


Fig. IV-4

Effect of Sodium Chloride addition on Calibration Curve for Phosphorus

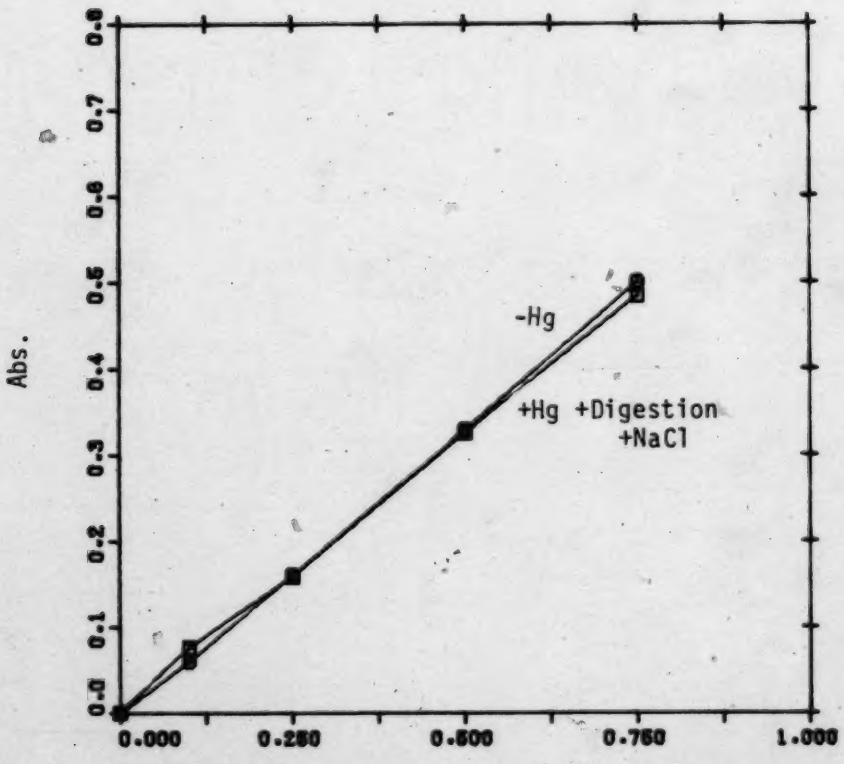


Fig. IV-5

Effect of Neutralization of Sample on Calibration Curve for Phosphorus

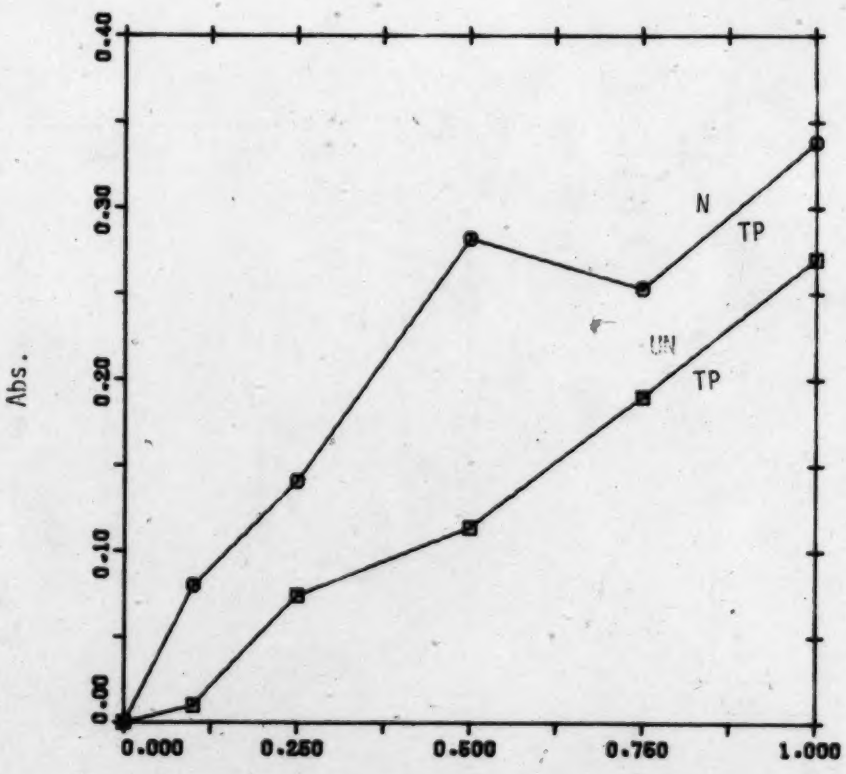


Fig. IV-6

produced lower results, though a straight line calibration curve was obtained. Only high concentrations of PO_4, showed the turbidity effect for samples neutralized with NaOH. To overcome the above effect, potassium persulphate instead of ammonium persulphate was used in the digestion procedure. The turbidity was removed and a linear calibration curve up to a PO_4 concentration of 0.25 mg P/L was obtained (Fig.IV-7). All the greywater samples were diluted to obtain an absorbance measurement in the linear range.

Automated technique

The samples were also analysed using an autometed technique for phosphate according to method number 606 (APHA,1975) using the Technicon AutoAnalyzer II system with the addition of 50 mg/L NaCl. To check that the method was suitable for the samples concerned, a sample was spiked with four different concentrations of standard potassium dihydrogen phosphate (0.1, 0.2, 0.3, 0.4 mg/L). The mean % recovery of the 4 test concentration was found to be 85%. The results were similar to the results obtained by manual Ascorbic acid method. Therefore, the automated ascorbic acid method was used for all the samples analyzed in this project.

Nitrate Analysis

Nitrate is a difficult determination because of the

Effect of Potassium Persulfate on Calibration Curve for Phosphorus

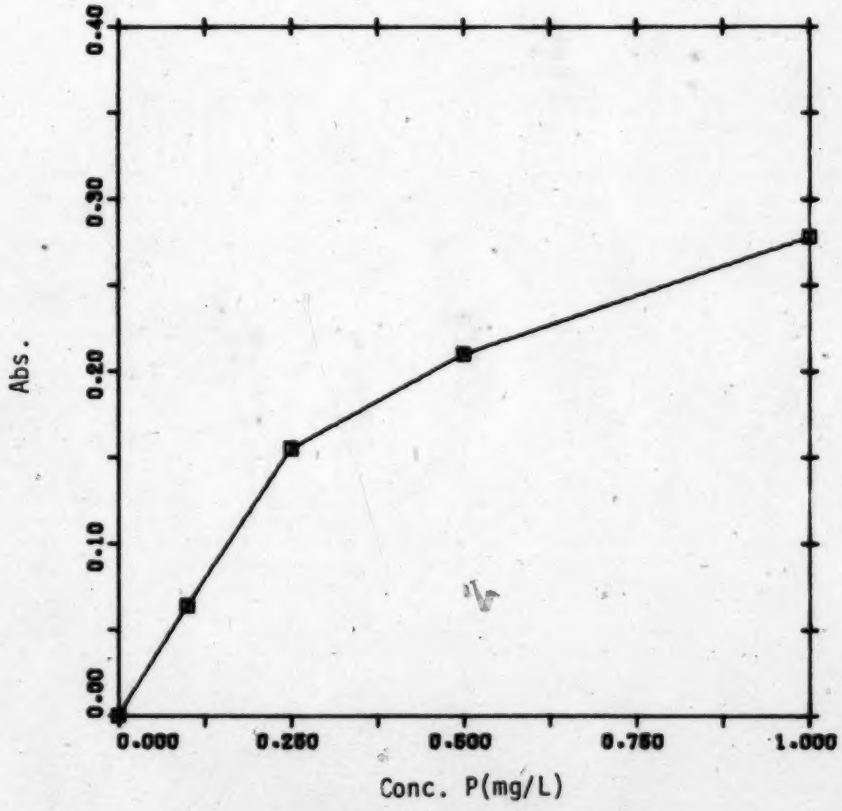


Fig. IV-7

high probability that interfering constituents will be present particularly in domestic wastewater samples.

Brucine method

Brucine method number 419D (APHA,1975) was found to be unsuitable for determining NO_3-N in greywater samples. The calibration curve was not linear as shown in Figure IV-8. Also, spiking the samples with standard potassium nitrate gave a recovery of only 43%.

Cadmium reduction method

Cadmium reduction method number 419C (APHA,1975) was examined for determination of NO_3-N for greywater samples. This method was adopted with the reduction of sample size to 10 mL which required 0.2 mL of sulfanilamide solution and 0.2 mL 1-naphthyl-ethylenediamine solution for color development. The NO_2-N and NO_3-N calibration curves are shown in Figures IV-9 and IV-10 respectively.

The samples from Whale Cove were preserved with 40 mg/L $HgCl_2$ and filtered with acid washed 0.45 micrometer millipore filter paper. The samples obtained from the greywater septic tank from the home in Strathcona County were analysed on the same day. However, difficulties were encountered in the reduction by the cadmium column.

Calibration Curve for Nitrate Determination
using Brucine Method

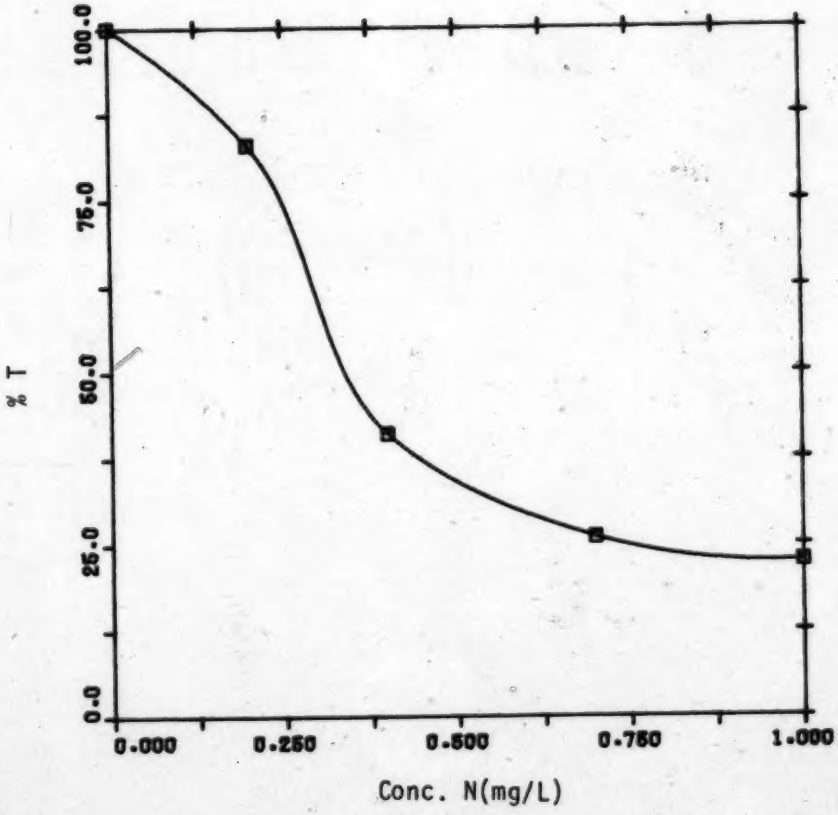


Fig. IV-8

Calibration Curve for Nitrite Determination
using Cadmium Reduction Method

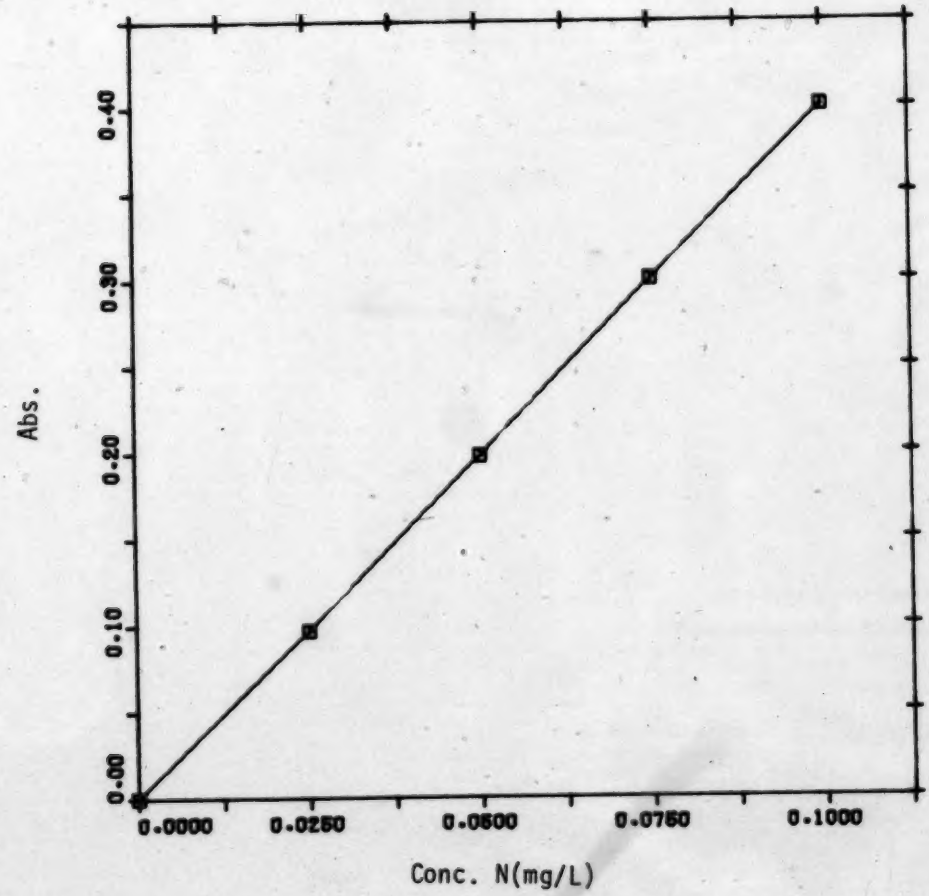


Fig. IV-9

Calibration Curve for Nitrate Determination
using Cadmium Reduction Method

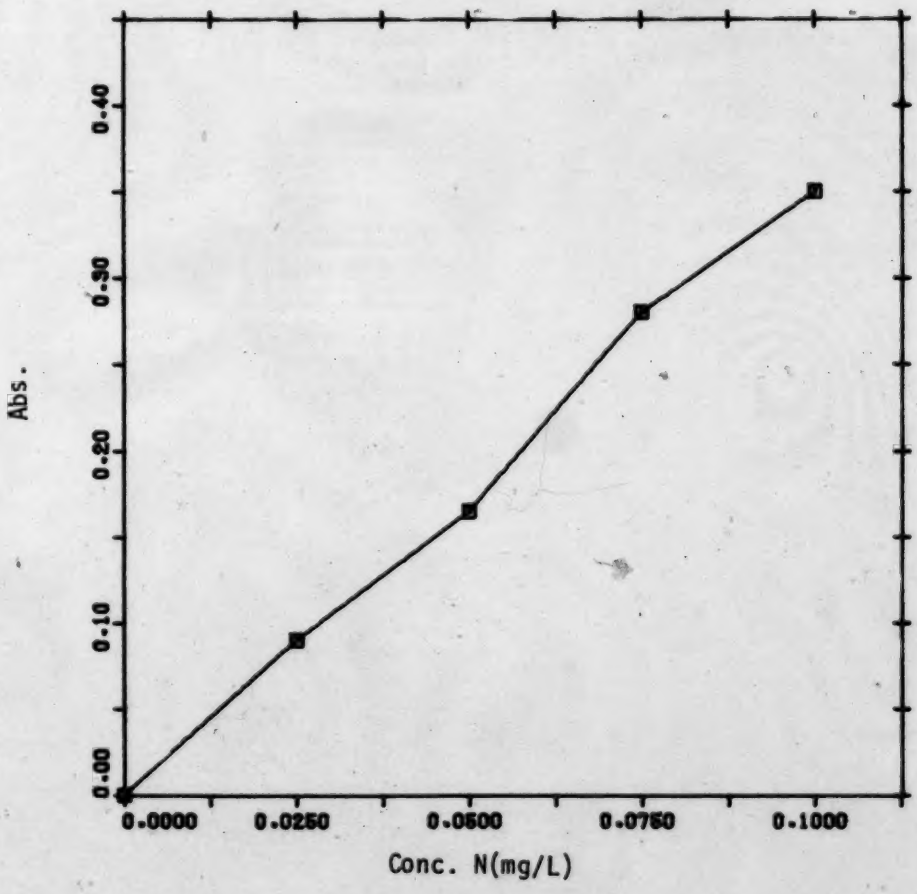


Fig. IV-IO

The efficiency of the cadmium column dropped drastically after passing about three samples through the column. Adjusting the pH of samples did not solve this problem. Available time did not permit a thorough investigation of the difficulties encountered with manual cadmium reduction method. Thus, the method was abandoned for automated cadmium method number 605. (APHA,1975) By this method the cadmium column efficiency was not affected by the samples. However, only a negligible amount of NO_3-N was present in greywater samples. Therefore nitrates were not detected since the lower detection limit of the method is 0.5 mg/L. To verify that negligible amounts of NO_3-N were present in the greywater samples, the method was tested by spiking 2 samples. For both samples, 100% recovery was noted when 0.3 and 0.4 mg/L spiking concentrations were used. The above results show that there are no interferences present in the sample that would make the method unsuitable for determining NO_3-N in greywater. All the samples were analysed for NO_3-N using the automated cadmium reduction method. With the exception of one sample from Whale Cove (0.5 mg/L NO_3-N), none of the samples showed any detectable amount of NO_3-N. This sample was taken from laundry washwater from a family of 5, two adults and 3 children of ages 12, 3 and 2.

Ammonia Analysis

Ammonia-nitrogen was determined by automated phenate

method using the AutoAnalyzer II system. The method adopted was the one issued by Technicon Industrial systems and is provided in the Appendix.

The samples from Whale Cove were preserved with 1 mL/L concentrated sulphuric acid. The samples from Edmonton were refrigerated at 0^0C and analyses on these samples were performed on a weekly basis. To remove color in the samples, 25 mL portions of samples were distilled using borate buffer solution and collected in sulphuric acid.

Nine greywater samples from Edmonton were analyzed using the acidimetric method number 418D (APHA,1975). In most of the samples, ammonia was not detected, showing that if any NH_3 was present, it was present in very low amounts (below 0.5 mg/L). Concentration values of below 0.5 mg/L were obtained from the automated phenate method. Thus spiking experiments were not performed for NH_3-N analyses.

Total Kjeldahl Nitrogen Analysis

TKN was determined according to the procedure outlined in method number 421 (APHA,1975) followed by titrimetric detection outlined in method 418D (APHA,1975). A 250 mL sample was digested for two and a half hours. The digestion time was kept constant for samples and blanks. Spiking experiments were not performed to determine the suitability of this method.

The analysis was performed on a daily basis on fresh samples obtained from the home in Edmonton.

B. RESULTS

The data generated from the project are listed in the appendix in tables A1-A3. The plots of pollutant parameters with respect ot time fail to indicate any obvious systematic variation (Figures IV-11 to IV-27). If this is so, then the fluctuations are random and a normal distribution may apply. However, for all the parameters examined, plots of cumulative probability versus concentration (Figs. A1-A16), demonstrated that the data do not follow a normal distribution. The data is found to possibly follow a log normal distribution. A Kolmogorov-Smirmov, goodness of fit test was performed to ascertain the null hypothesis that the data follows a log normal distribution. Since, for most of the parameters the observed D is less than the critical value at a significant level of 20% (tables IV-4 and IV-5) we do not have sufficient evidence to warrant rejection of the null hypothesis and a log normal distribution was appropriate.

For a log normal distribution, the geometric mean is the most efficient estimator for measuring the central value of the distribution. Tables IV-1 to IV-5 show the geometric means, and standard deviations for the three sets of data.

From the Figures A17 to A32, it is clear that, normally a large scatter in the values derived from chemical and bacteriological analyses must be expected.

In routine bacteriological analysis, a considerable spread in results must be expected. In addition, one could

Total Coliform Analysis: Whale Cove

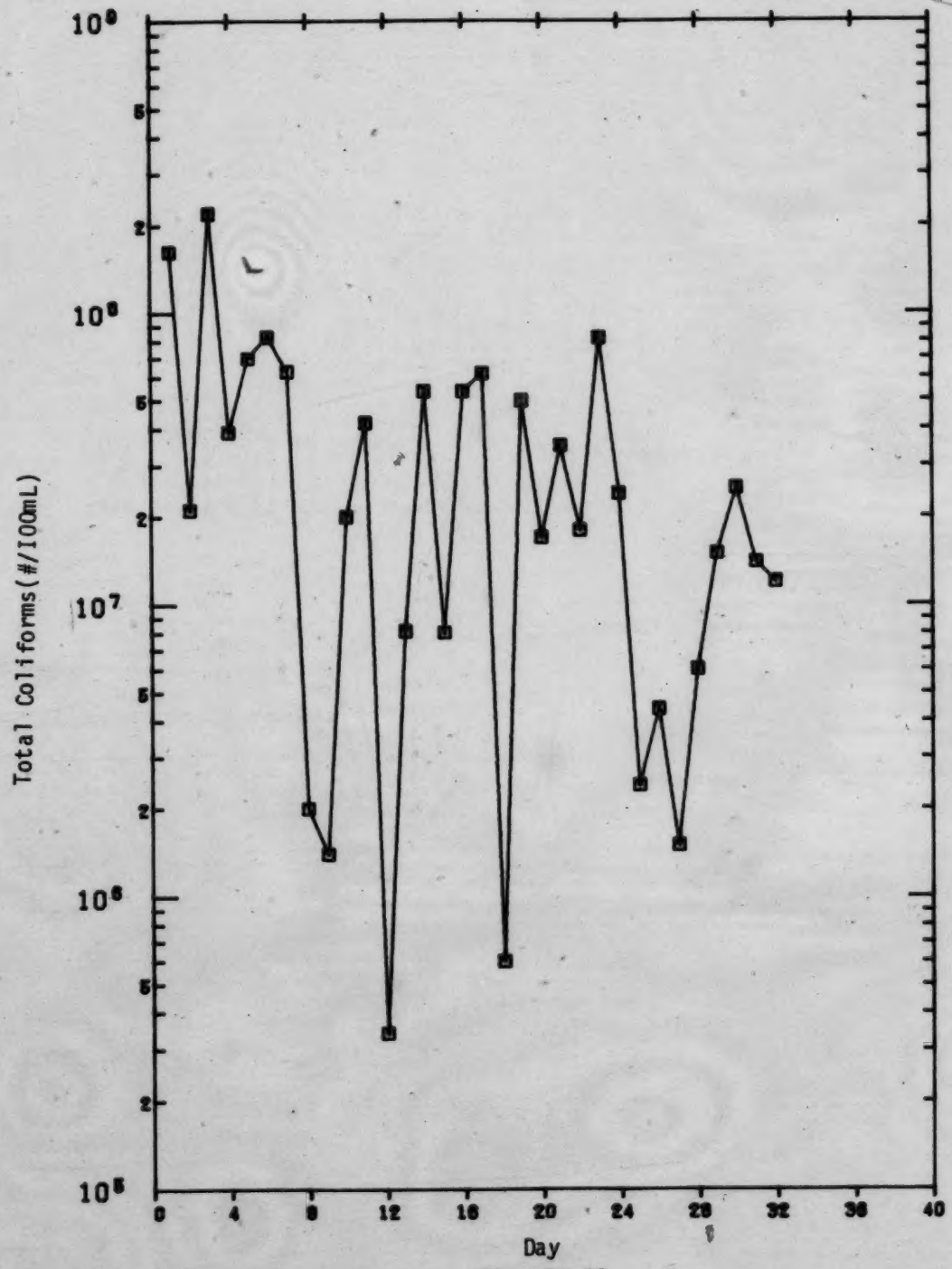


Fig. IV-II

Fecal Coliform Analysis: Whale Cove

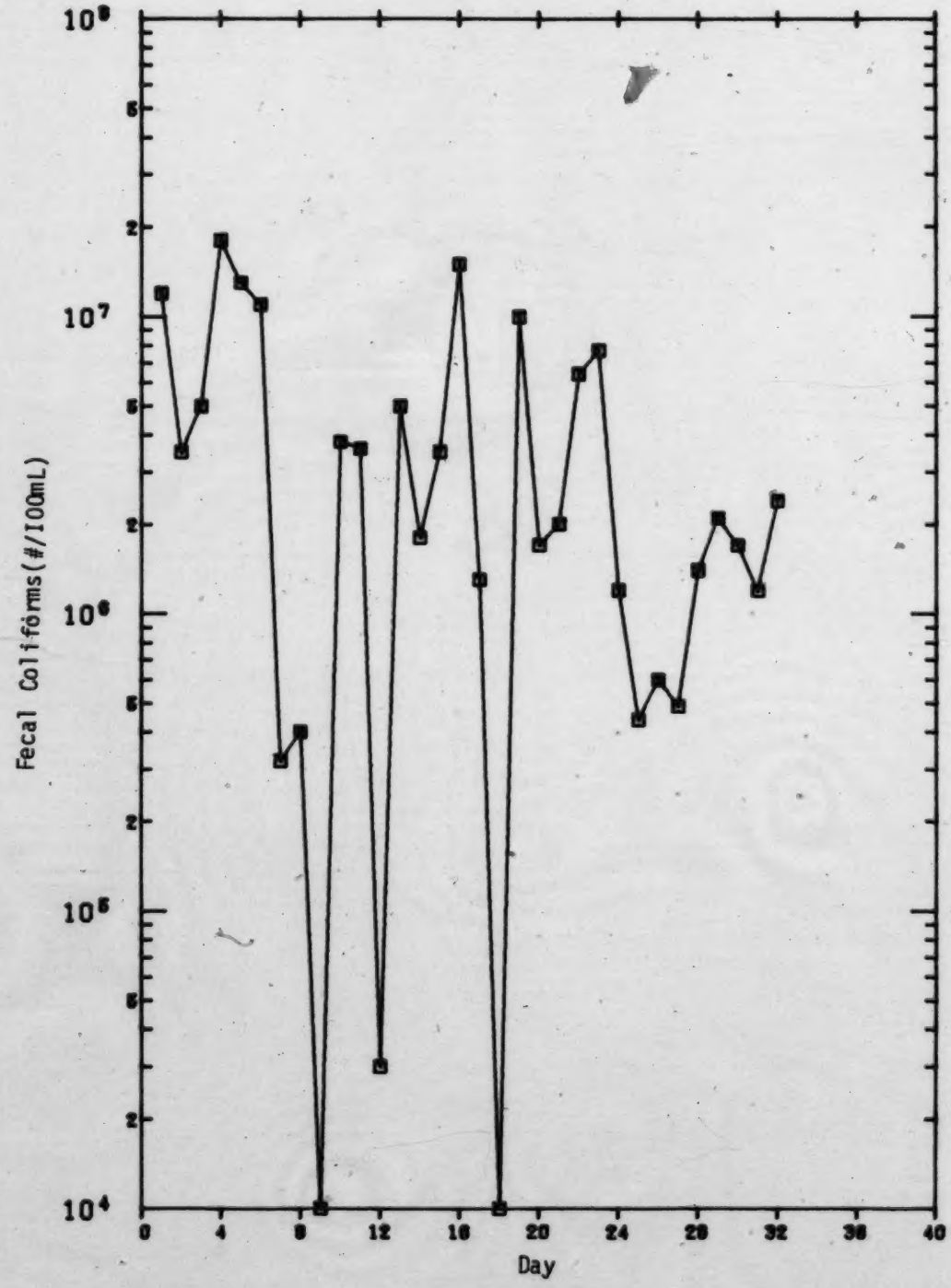


Fig. IV-I2

Fecal Strep. Analysis: Whale Cove

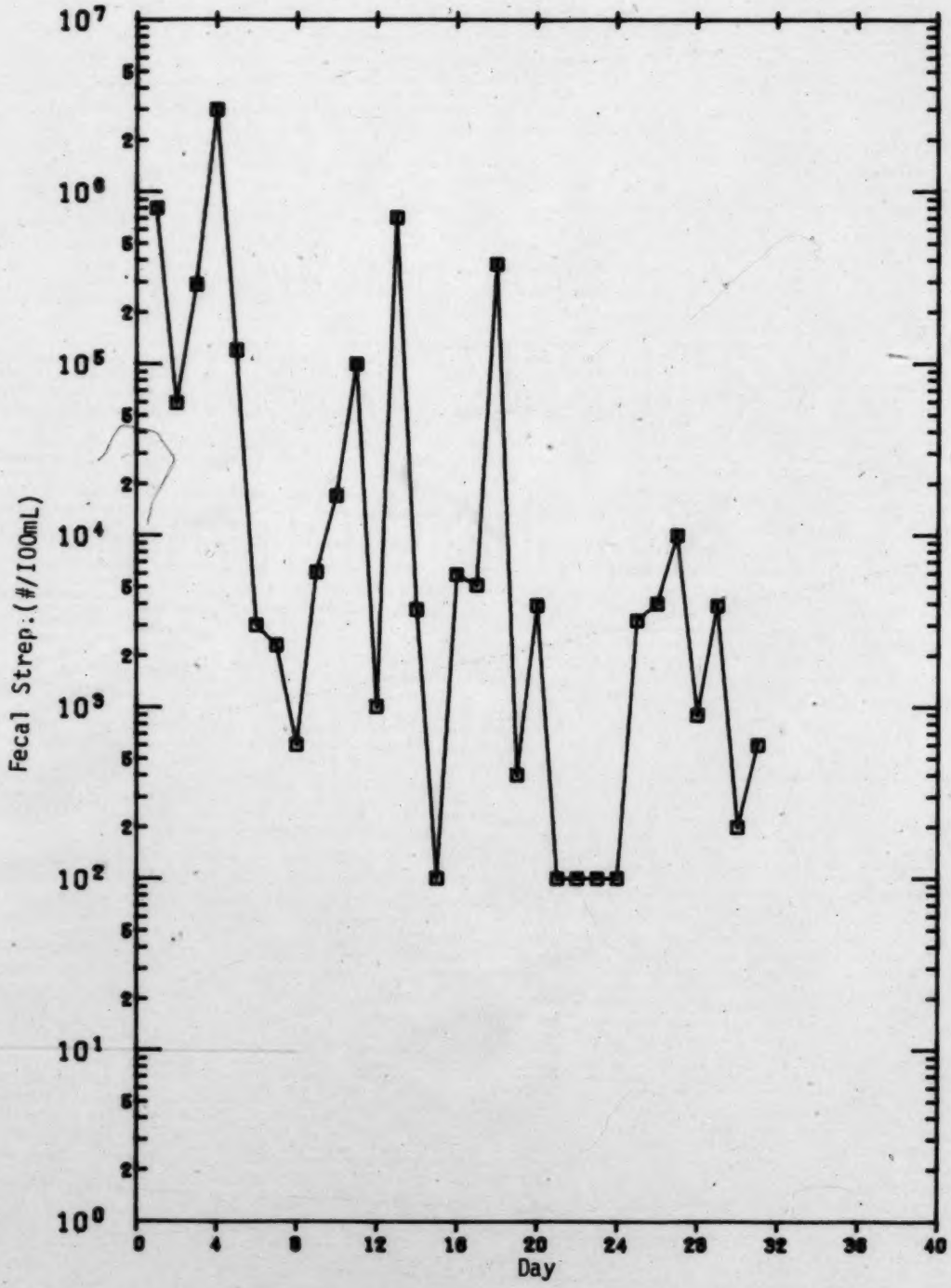


Fig. IV-I3

TOC Analysis: Whale Cove

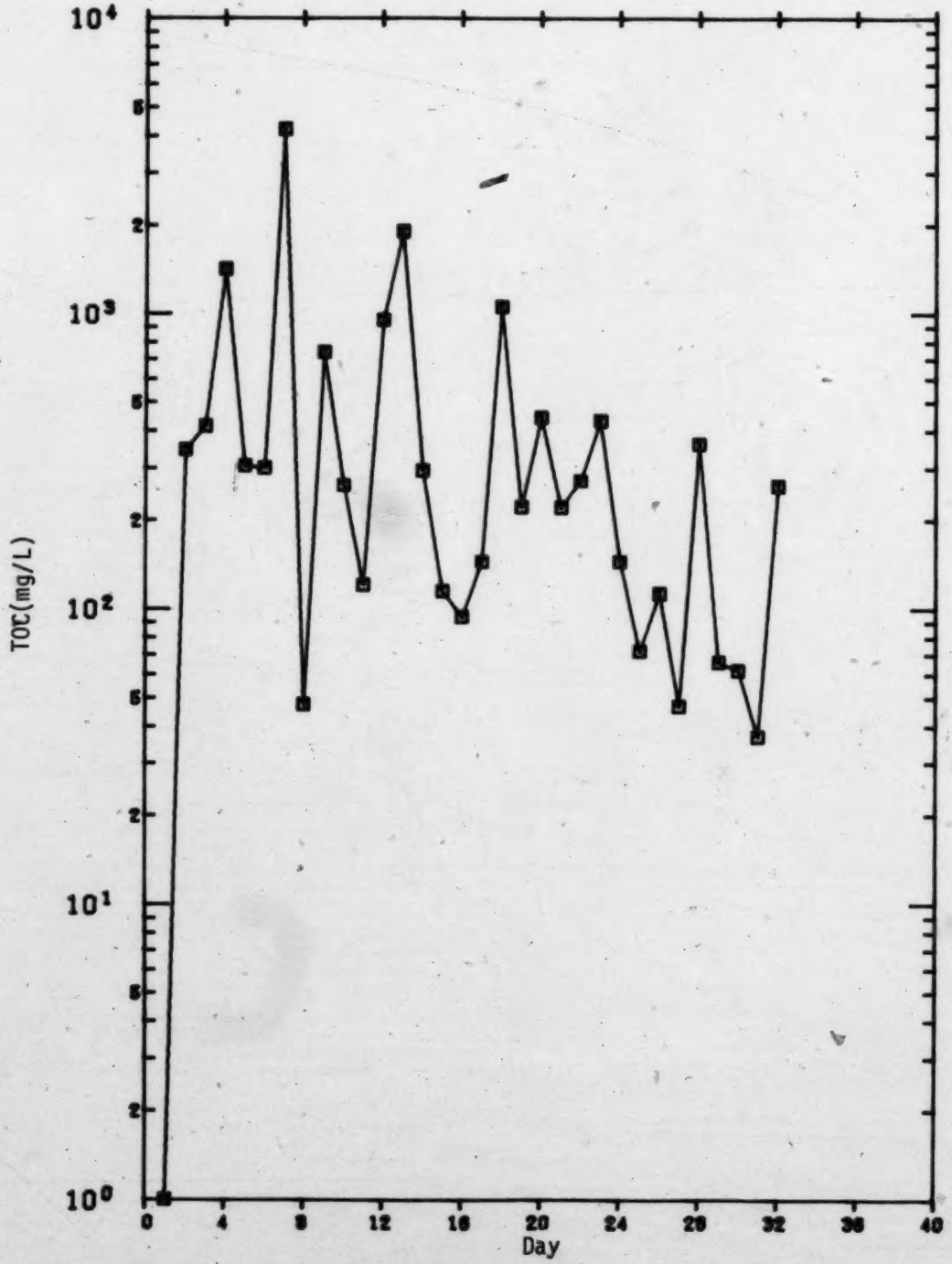


Fig. IV-I4

S. Solids Analysis: Whale Cove

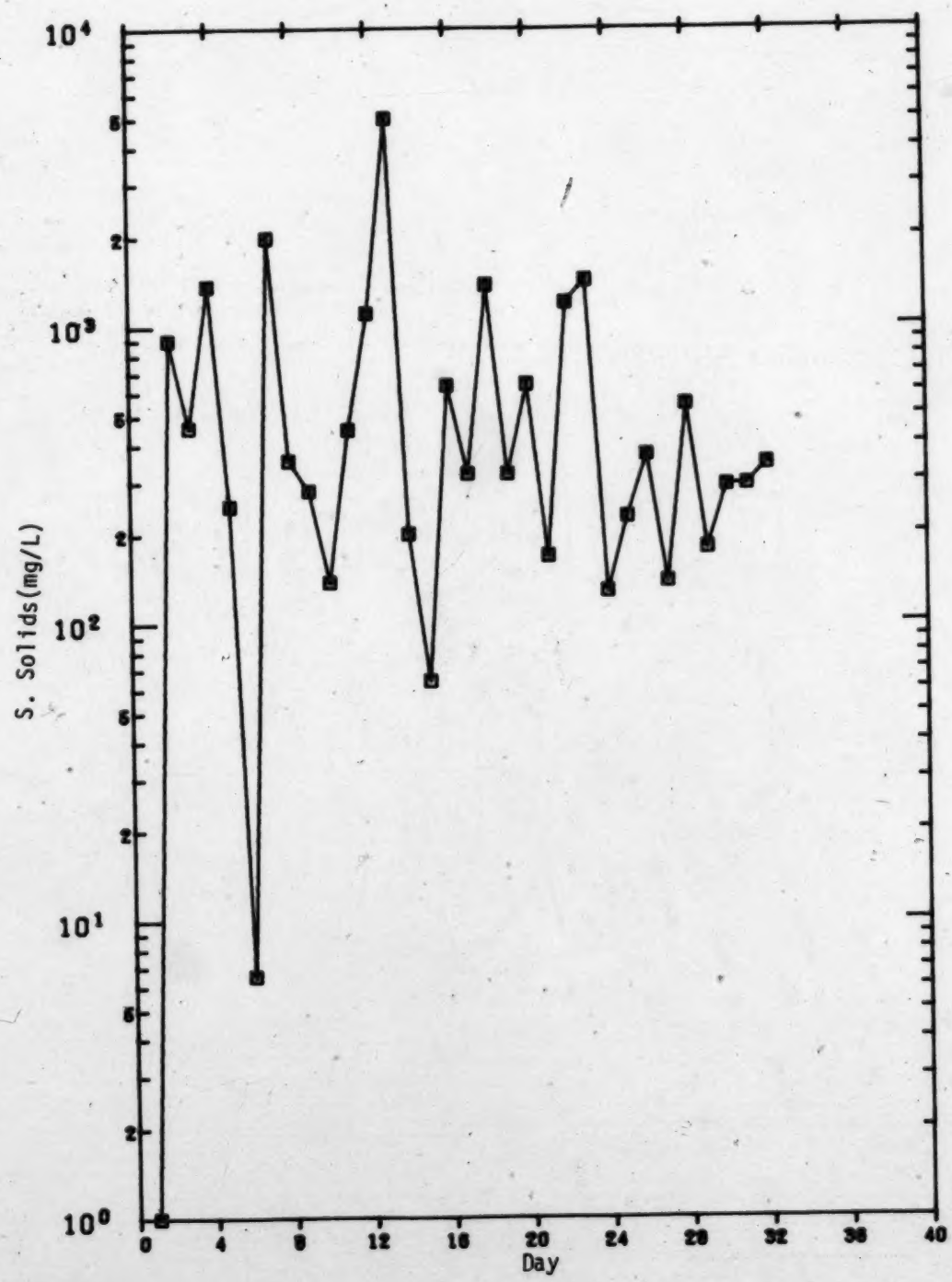


Fig. IV-I5

T-PO_4 Analysis: Whale Cove

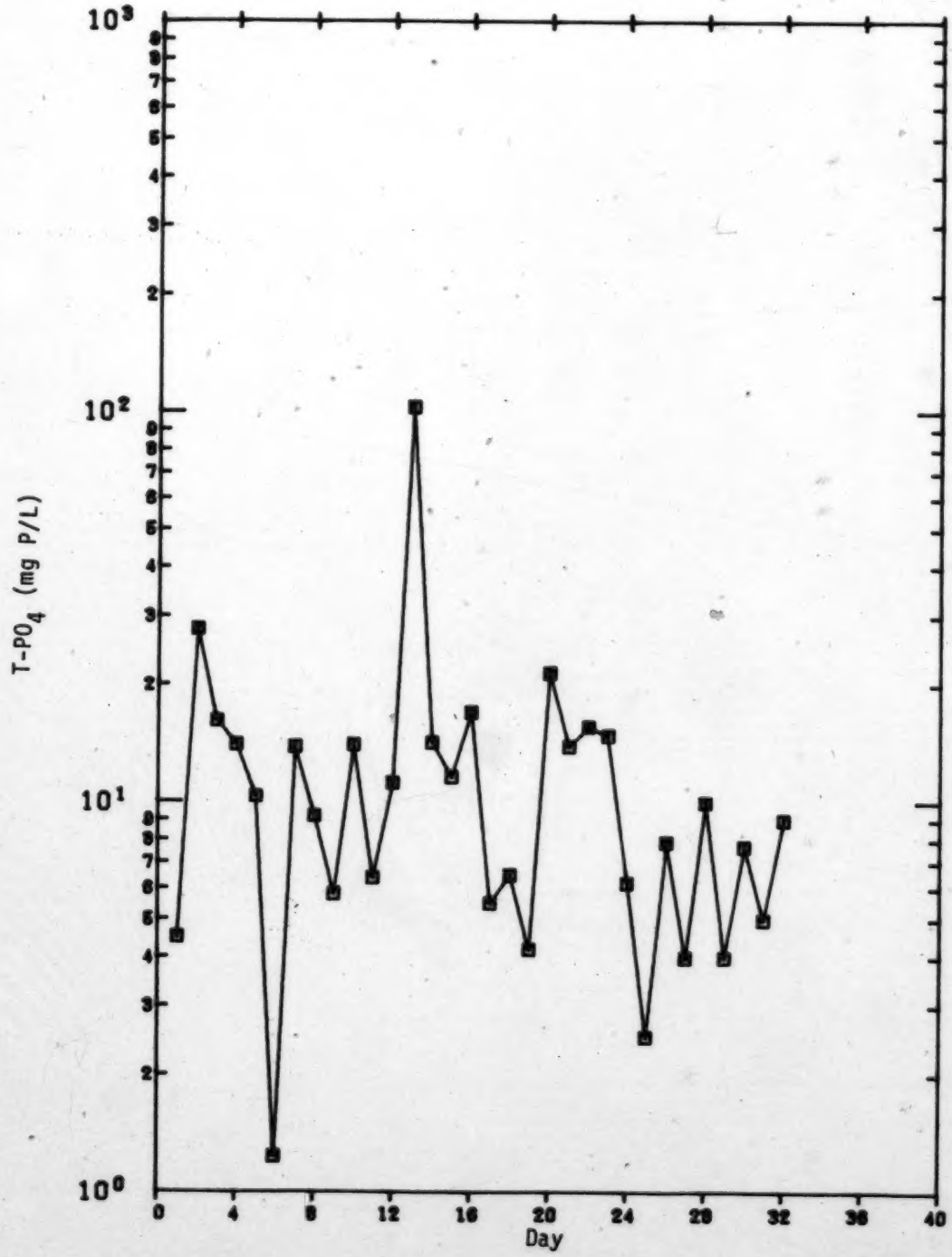


Fig. IV-I6

$O\text{-}PO_4$ Analysis: Whale Cove

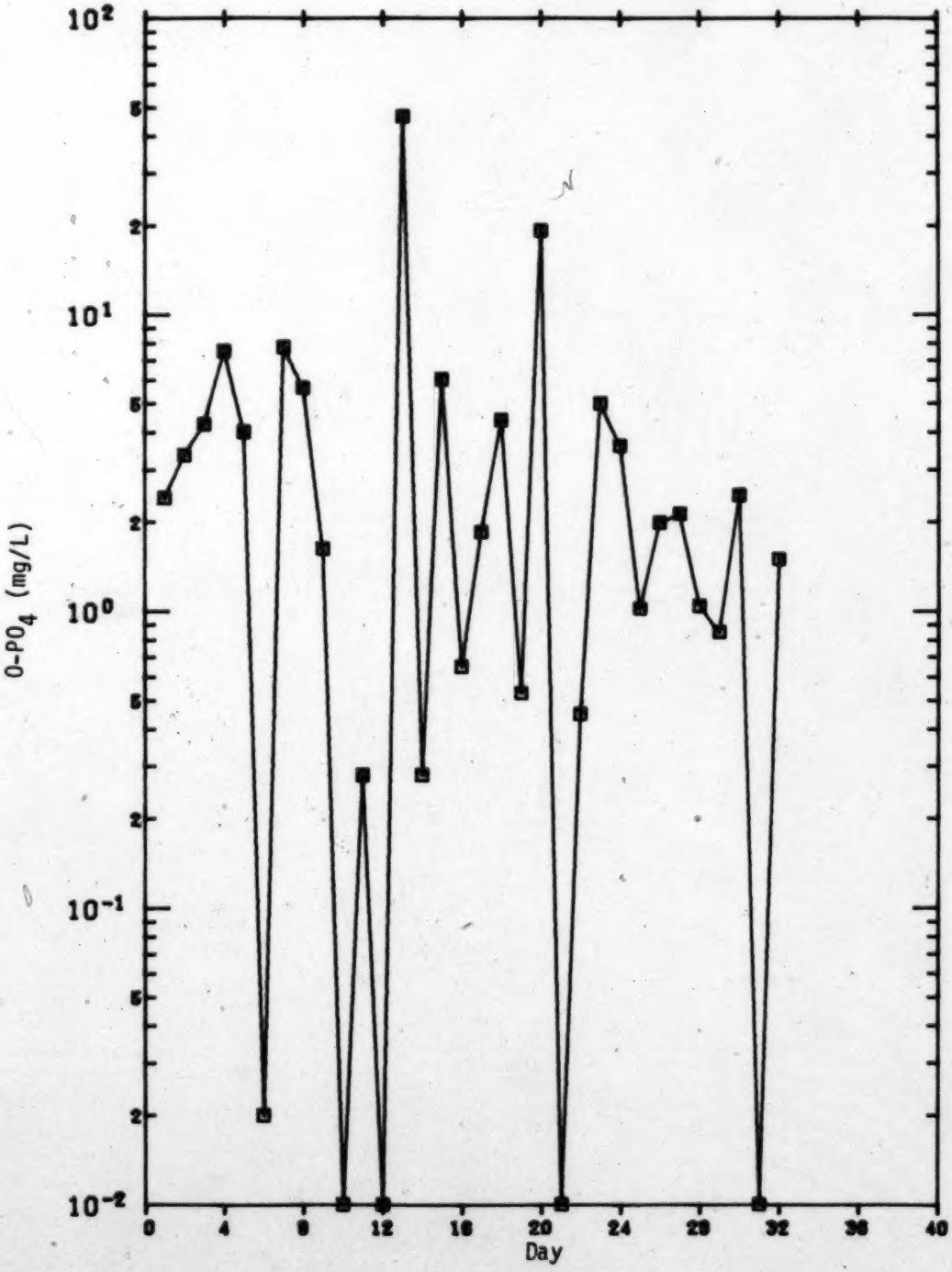


Fig. IV-I7

Ammonia Analysis: Whale Cove

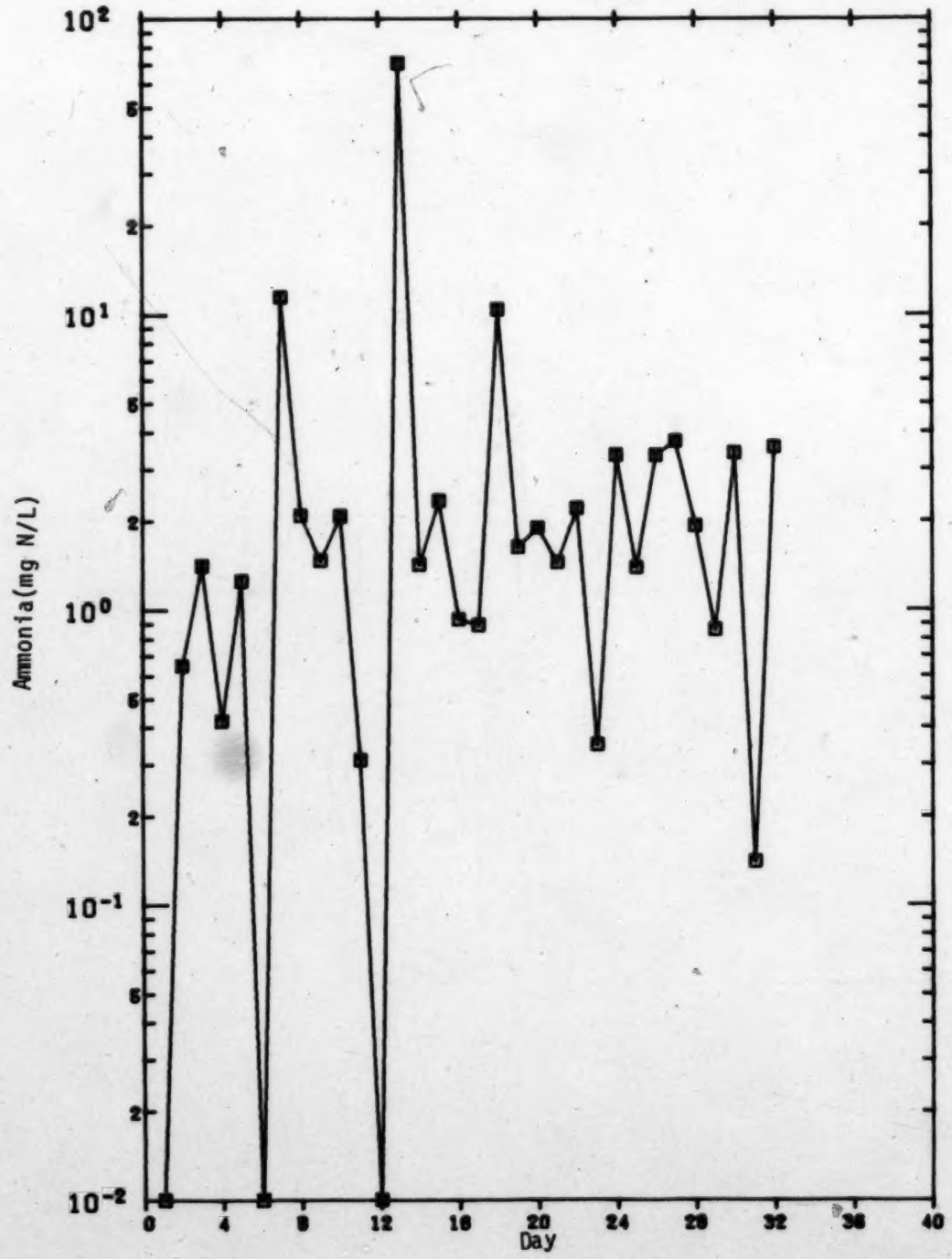


Fig. IV-I8

Nitrate Analysis: Whale Cove

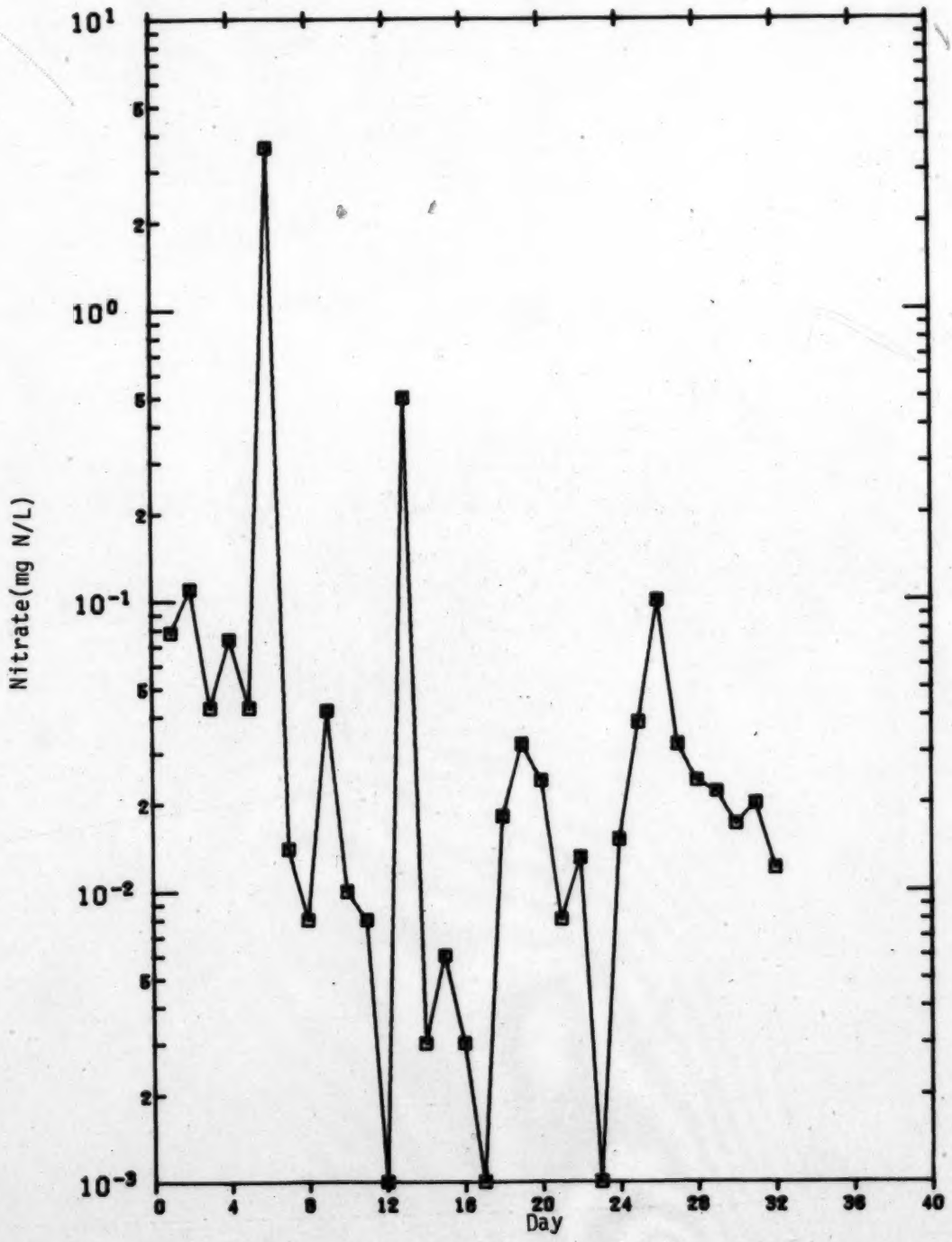


Fig. IV-I9

Total Coliform Analysis: Edmonton

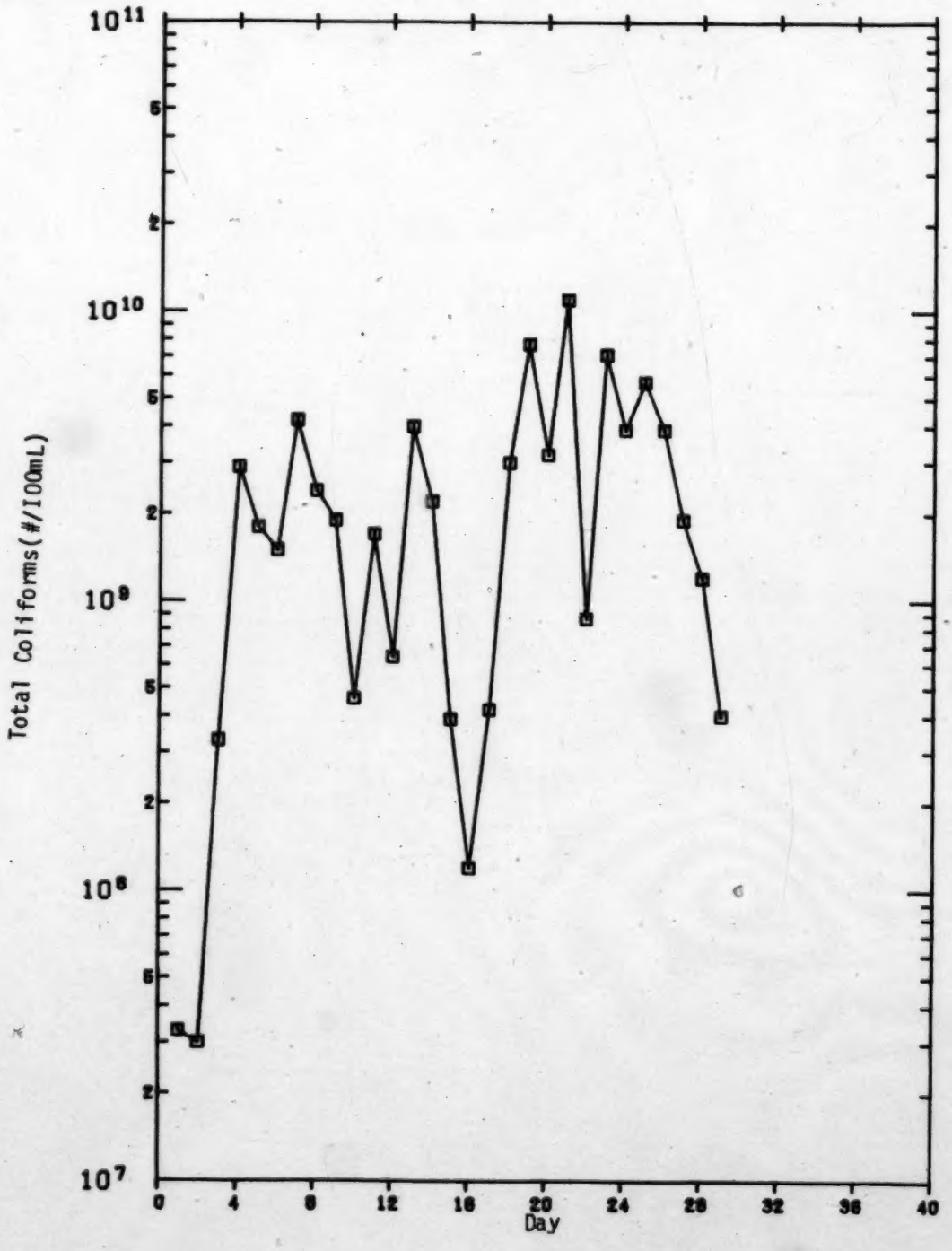


Fig. IV-20

Fecal Coliform Analysis: Edmonton

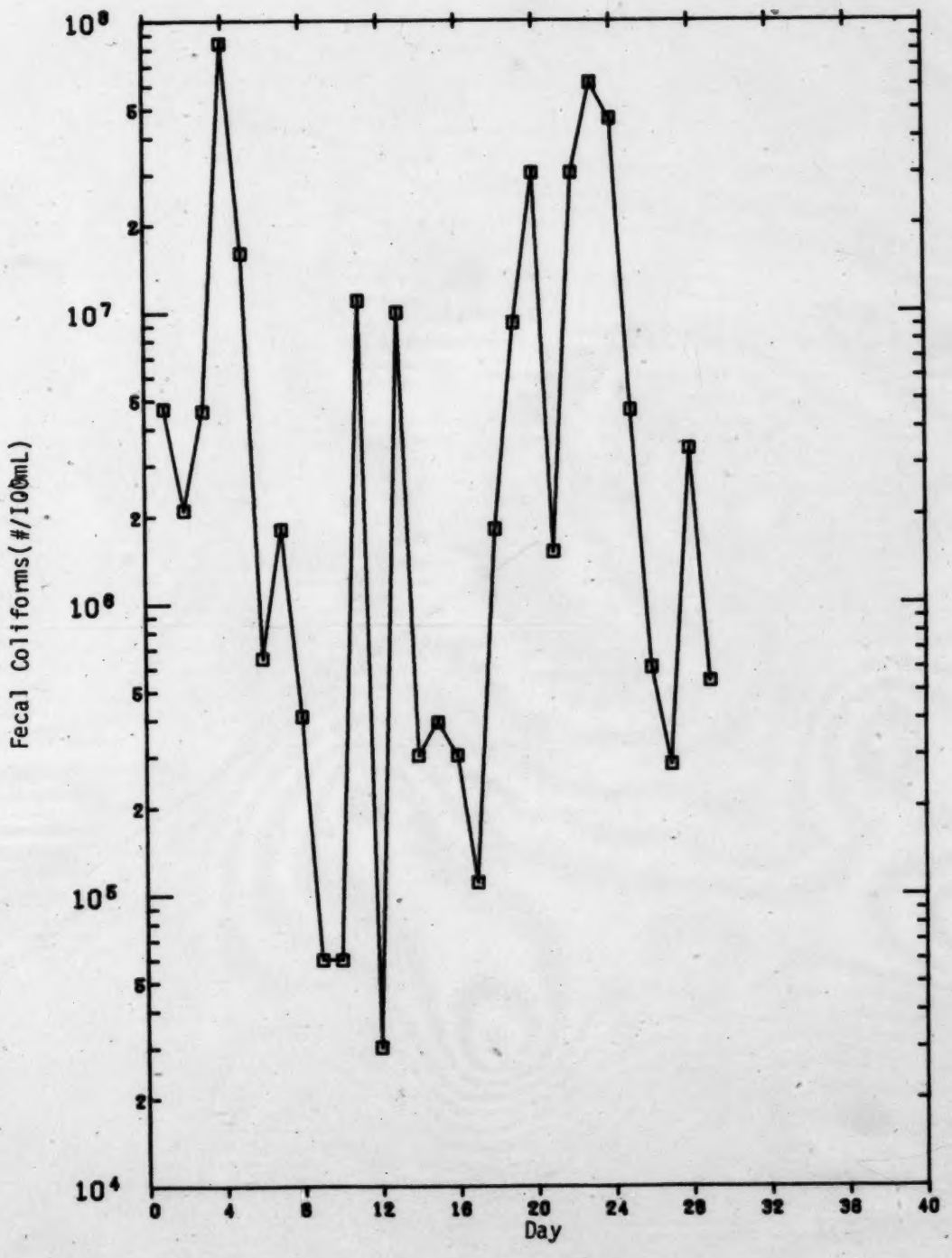


Fig. IV-2I

F. Strep. Analysis: Edmonton

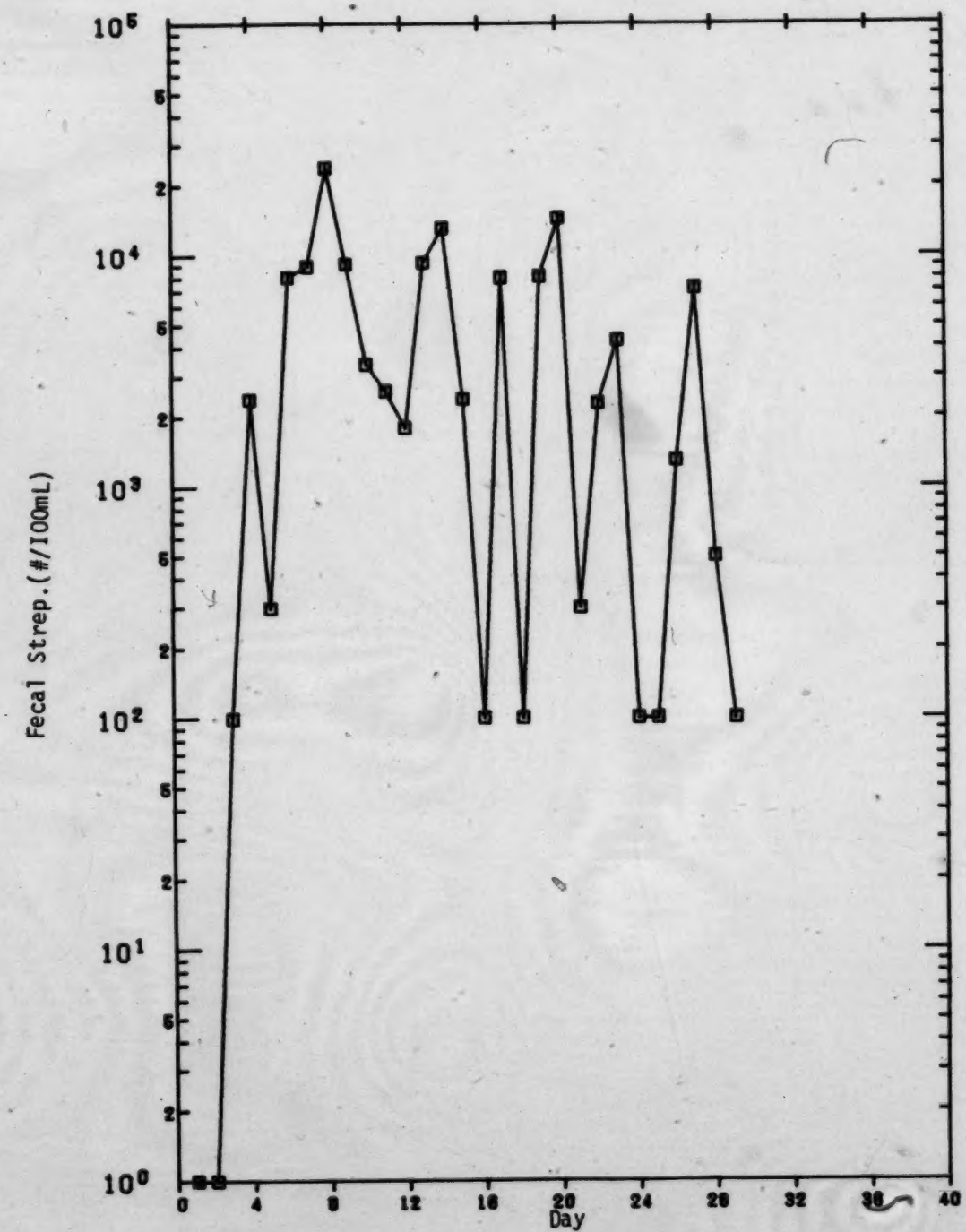


Fig. IV-22

TOC Analysis: Edmonton

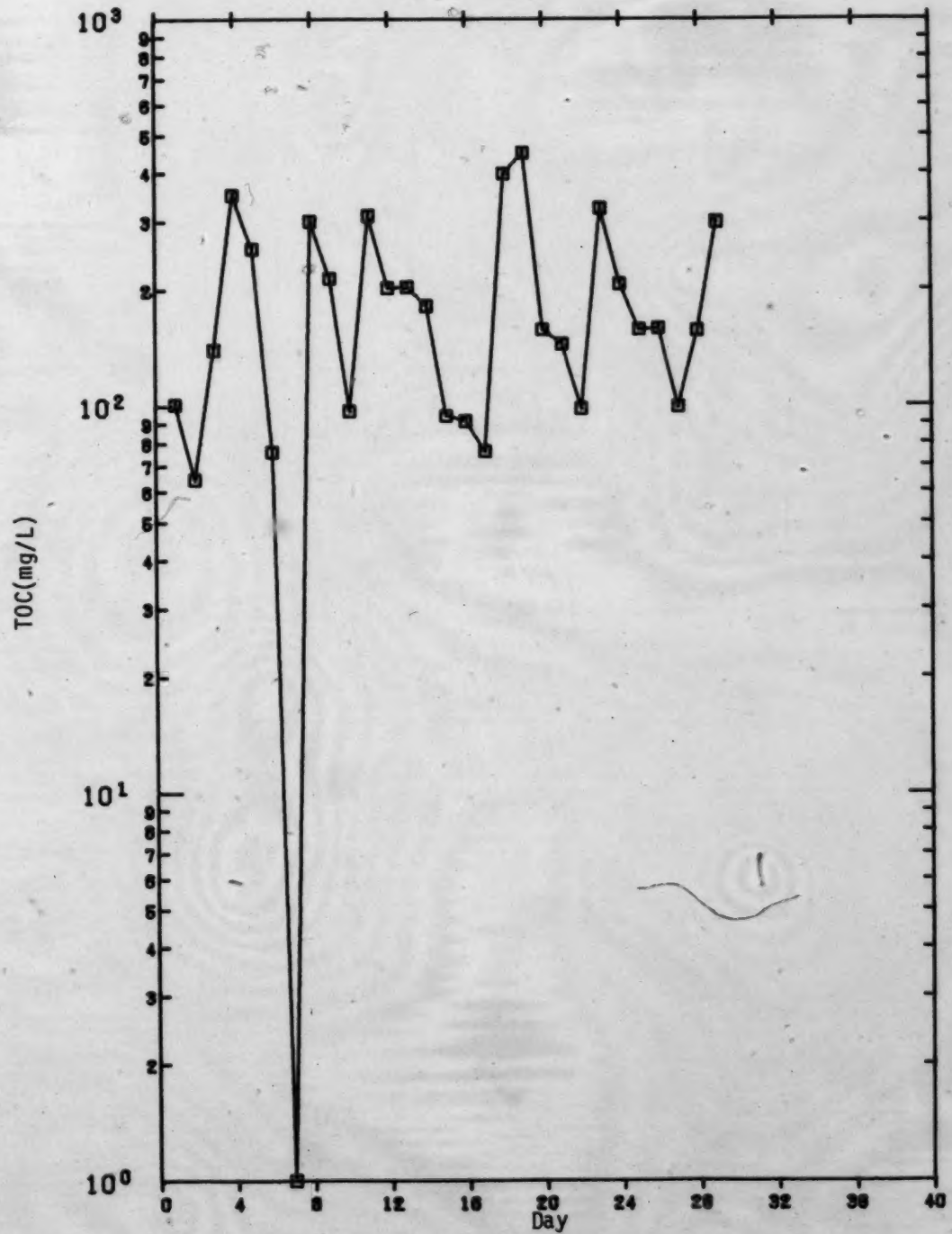


Fig. IV-23

S. Solids Analysis: Edmonton

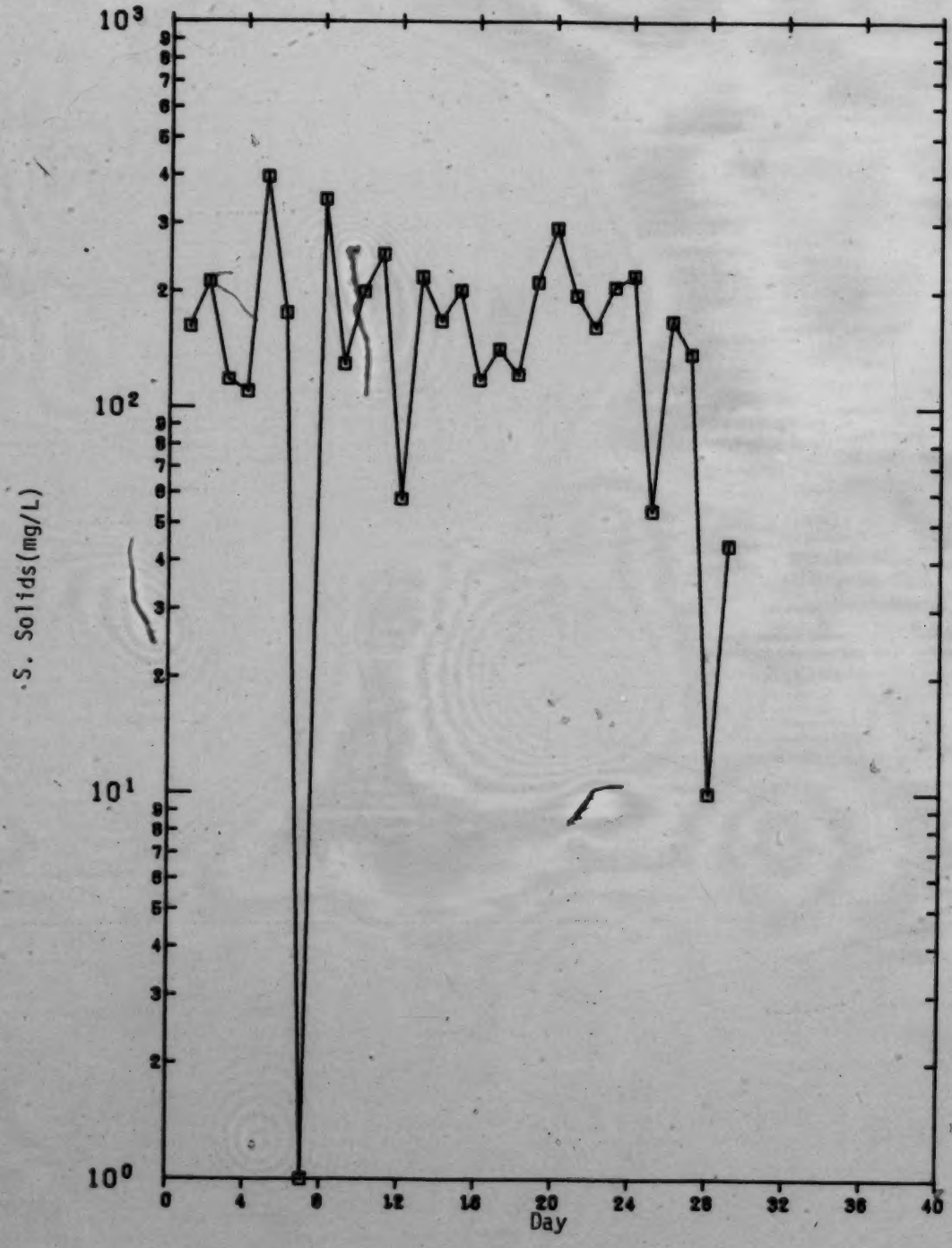


Fig. IV-24

T-PO_4 Analysis: Edmonton

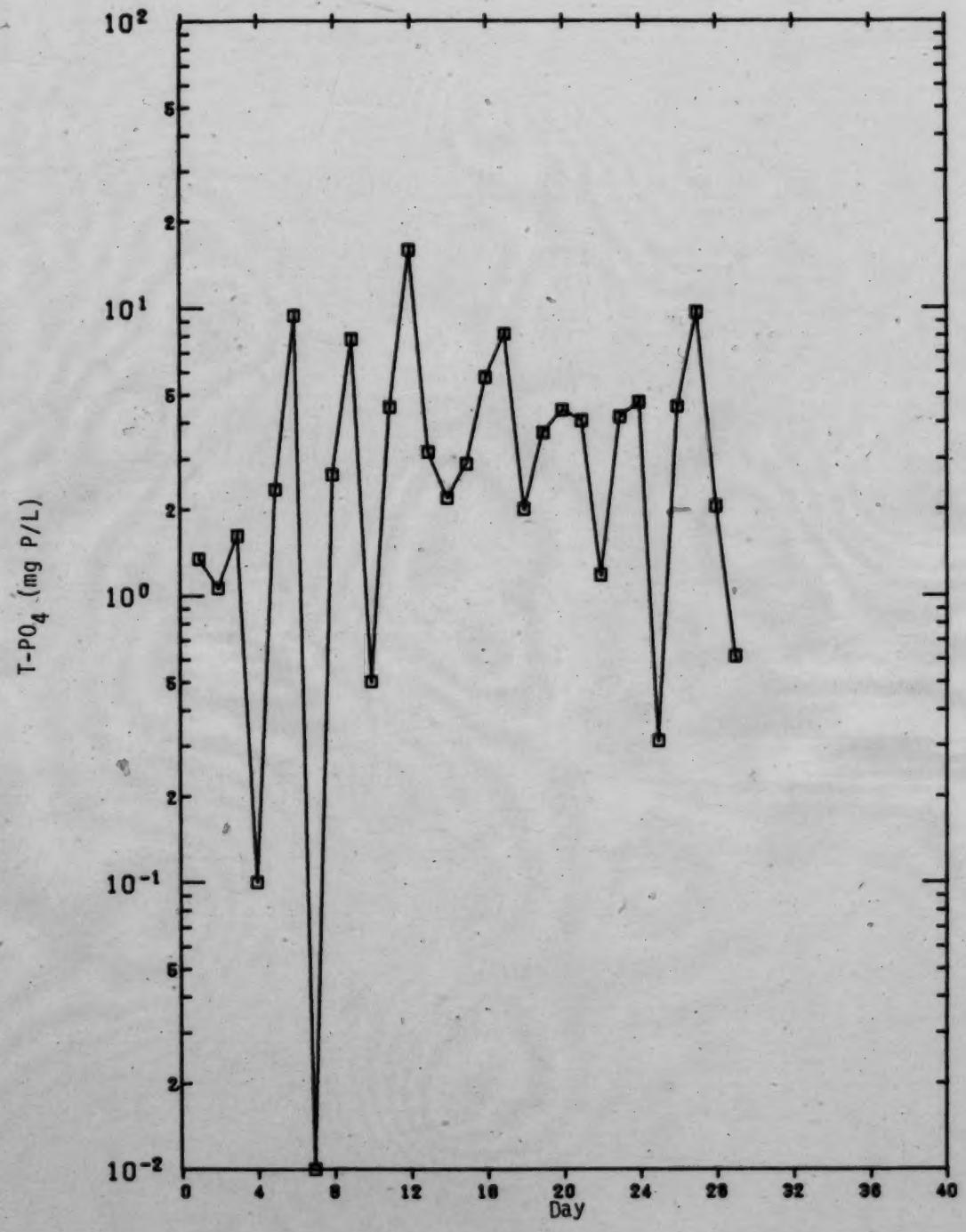


Fig. IV-25

$O\text{-}PO_4$ Analysis: Edmonton

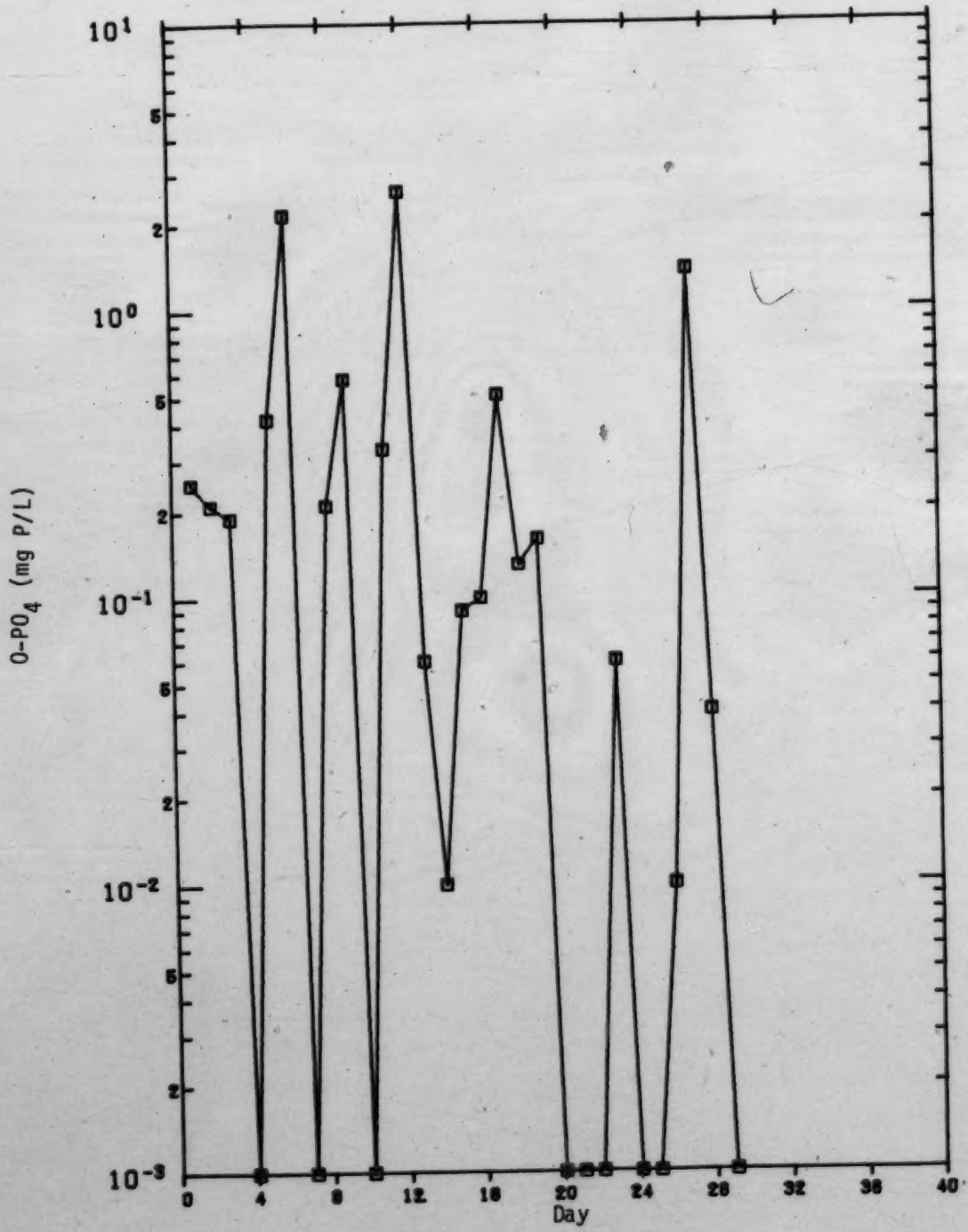


Fig. IV-26

Ammonia Analysis: Edmonton

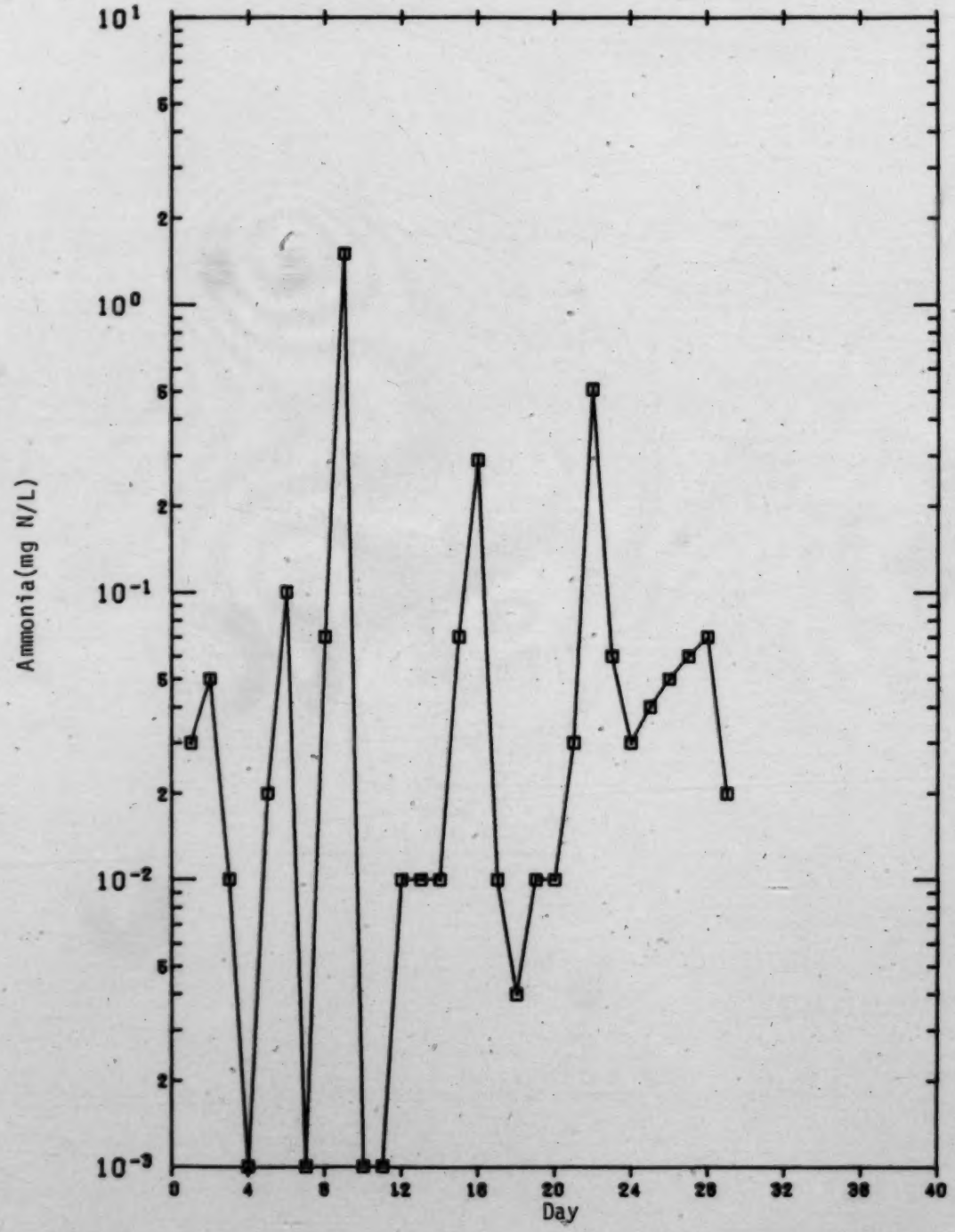


Fig. IV-27

TABLE IV-1

Grey Water Characteristics from Sampling Site, Strathcona County: July 6 to July 14, 1978

Parameter	geom. mean	log. std. deviation	geom. mean + 1 s.d.	geom. mean - 1 s.d.
Total coli	8.8×10^6	0.I5	1.1×10^7	5.6×10^6
Fecal coli	4.3×10^6	0.26	7.3×10^6	2.2×10^6
Fecal strep.	4.1×10^4	0.3I	8.1×10^4	1.9×10^4

TABLE IV-2

Grey Water Characteristics of Winter Samples from Strathcona County: Jan. 16 to Jan. 24, 1979

Parameter	Geom. mean	log. std. deviation	Geom. mean + 1 s.d.	Geom. mean - 1 s.d.
Total coli	1.1×10^7	0.84	7.0×10^7	1.4×10^6
Fecal coli	1.8×10^6	0.40	5.1×10^6	7.9×10^5
Fecal strep	1.2×10^3	I.44	3.5×10^4	4.6×10^1
TOC (mg/L)	112.3	0.24	173	57.5
S. Solids (mg/L)	247.3	0.32	522.2	120.2
T-PO_4 (mg/L)	3.58	0.I4	4.84	2.57
O-PO_4 (mg/L)	3.20	0.I2	4.2	2.40
NH_3 (mg/L)	0.06	0.65	0.28	0.01

Total coliforms, Fecal coliforms, & Fecal strep. measured as # per 100mL.

TABLE IV-3

Grey Water Characteristics of Summer & Winter Samples from Strathcona County

Parameter	geom. mean	log. std. deviation	geom. mean + 1 s.d.	geom. mean - 1 s.d.
Total coli	9.8×10^6	0.58	3.8×10^7	2.6×10^6
Fecal coli	2.6×10^6	0.39	6.1×10^6	1.0×10^6
Fecal strep	8.1×10^3	I.24	1.4×10^5	4.6×10^2

TABLE IV-4

Grey Water Characteristics of Samples
from Whale Cove: Aug. 2 to Sept. 16, 1978

Parameter	Geom. mean	log. std. deviation	Geom. mean + 1 s.d.	Geom. mean - 1 s.d.	K. S. test	
					$d_{max.}$	d at 20%
Total coliforms	1.5×10^7	0.69	7.9×10^7	3.2×10^6	0.13	0.19
Fecal coliforms	1.2×10^6	I.35	2.8×10^7	5.6×10^4	0.18	0.19
Fecal strep	1.0×10^4	I.20	1.6×10^5	6.3×10^2	0.24	0.21
TOC (mg/L)	210	0.66	910	44	0.11	0.19
S. solids (mg/L)	294.3	0.84	2040	43	0.17	0.19
T-PO_4 (mg/L)	9.2	0.35	21	4.2	0.15	0.19
O-PO_4 (mg/L)	1.9	0.8I	11.9	0.29	0.17	0.19
NH_3 (mg/L)	1.41	0.77	8.34	0.24	0.16	0.19

Total coliforms, Fecal coliforms, & Fecal strep. measured as # per 100mL.

K. S. = Kolmogorov-Smirmov

TABLE IV-5

Grey Water Characteristics of Samples
from Edmonton: Feb. 26 to March 29, 1979

Parameter	Geom. mean	log. std. deviation	Geom. mean + 1 s.d.	Geom. mean - 1 s.d.	K. S. test	
					$d_{max.}$	d at 20%
Total coliforms	1.1×10^9	0.77	6.7×10^9	1.9×10^8	0.17	0.19
Fecal coliforms	2.0×10^6	0.96	1.8×10^7	2.2×10^5	0.09	0.19
Fecal strep.	3.4×10^3	0.62	1.4×10^4	8.1×10^2	0.32	0.19
TOC (mg/L)	142	0.49	436.1	45.7	0.27	0.19
S. solids (mg/L)	116	0.54	411	33.9	0.30	0.19
T-PO_4 (mg/L)	2.08	0.78	12.53	0.35	0.13	0.19
O-PO_4 (mg/L)	0.17	0.82	1.12	0.03	0.28	0.244
NH_3 (mg/L)	0.04	I.04	0.43	0.0035	0.155	0.284
TKN (mg/L)	7.18	0.27				

Total coliforms, Fecal coliforms and Fecal strep. measured as # per 100mL.

K. S. = Kolmogorov-Smirnov

expect a very great variation in the degree of pollutant loading in the greywater. This variation in concentration would seem to be sufficient to explain the very great spread which is characteristic of the analysis values of coliforms.

Olsson *et al* (1968), suggested that the bacterial contribution from the laundry water was of little importance mainly because of the presence of bactericidal constituents in detergents and because of the relative high temperatures used for the majority of washing cycles. However, one sample from Whale Cove that consisted entirely of laundry washwater showed a high concentration of phosphates as well as high concentration of coliforms. If coliforms survive in the laundry washwater, there is a greater possibility for viruses to survive since they are more resistant to disinfection than coliforms. Based upon a statistical analysis of the measured parameters, the dispersions about the mean values were found to be large as evidenced by large standard deviations and wide ranges. For example, the mean value for total phosphorus based on 30 samples was 9.2 mg/L with a log standard deviation of 0.35 mg/L for the set of data from Whale Cove and 2.08 mg/L with a log standard deviation of 0.78 mg/L for the data from Edmonton. One extreme value was noted for phosphate analysis. No error in analysis was found for this sample. Upon investigating the source of the sample, it was found that the sample contained laundry washwater only. Similarly, $O\text{-}PO_4$ and NH_3 show large standard deviations for both sets of data. But this is as

expected in light of the variations in day to day habits at a given home and the variations in the wastewater quality produced by the individual household events.

In order to justify using greywater samples from Edmonton for treatability experiments, t-tests were performed for all the parametrers to determine whether significant difference existed between the samples from Edmonton and samples from Whale Cove. The results are provided in table IV-6.

A summary of water use survey is presented in Figure IV-28 showing the total daily water usuage in a family of three. The amount of greywater produced is assumed to be equal to the amount of water used in the house excluding the amount of water used in toilet flushing.

The amount of water used, hence the amount of greywater produced can have two effects on the concentration of pollutant parameters. On the one hand, the greater the amount of water used, the larger the dilution available and hence concentrations might be expected to decrease accordingly. On the other hand, the greater amount of water used may be indicative of dirty household event discharges, which may cause an increase in concentration along with an increase in wastewater produced.

However, analyses of water use data and concentrations of pollution parameters show no correlation at all, for the Edmonton samples. (Figs. A33-A40 and table IV-7).

In general, the results from this study compare

TABLE IV-6

Results of t-test: Comparing Edmonton & Whale Cove Data

Parameter	n_1 Whale Cove Data	n_2 Edmonton Data	Degrees of Freedom	$t_{calc.}$	Significant level
Total coliforms	31	27	56	9.590	0.2%
Fecal coliforms	29	24	51	0.639	20%
Fecal strep.	25	19	42	1.554	20%
TOC	31	26	55	0.958	20%
S. solids	30	25	53	2.052	5%
$T\text{-}PO_4$	30	27	55	4.129	0.2%
$O\text{-}PO_4$	28	18	44	4.230	0.2%
NH_3	31	13	42	5.516	0.2%

Daily Water Usage: Edmonton

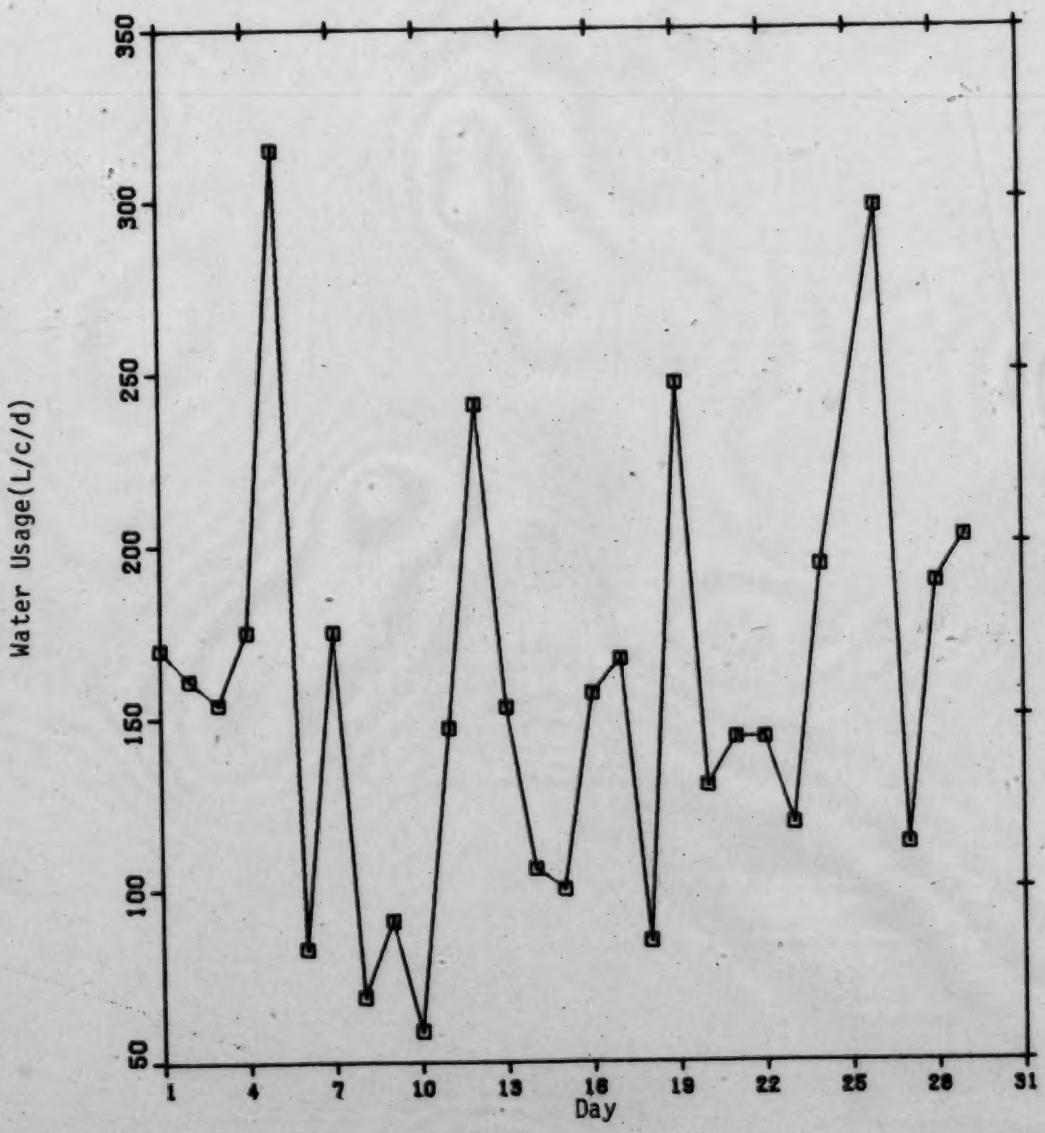


Fig. IV-28

TABLE IV-7

Correlation Coefficient Analysis

between water use & parameter

Parameter	Correlation Coefficient, r
Total coliforms	0.165
Fecal coliforms	0.247
Fecal strep.	-0.392
TOC	0.052
S. solids	0.117
$T\text{-}PO_4$	-0.042
$O\text{-}PO_4$	0.057
$NH_3\text{-}N$	0.11

favorably with those of earlier investigators. The major departure from data in the literature is with regard to chemical characteristics of greywater from Whale Cove. A substantially higher concentration of some chemical pollutants has been found than reported by other investigators. This difference is expected due to the reduced water usage in the homes in Whale Cove.

C. DISCUSSION

Relatively high concentrations of fecal and total coliforms organisms were observed in the greywater. The average concentration of fecal coliform organisms was as high as 2.0×10^6/100 mL (tableIV-4). Results of bacteriological analyses of samples from Whale Cove and from Strathcona County indicate the same order of magnitude, thus allowing the use of greywater from the South to be used in treatment experiments for greywater. However, due to sampling problems, the site in Strathcona County was abandoned and the sampling for treatability experiments was carried out in a home in Edmonton. The concentration of total coliforms from these samples were higher by a factor of 10^3 than the samples from Whale Cove. The t-test confirmed the result that the mean values of total coliforms are significantly different for the two sets of data. The result was found to be significant at 0.2% level, therefore the difference is highly significant. The reason for such high concentrations, is the ability of the total coliform

organisms to grow abundantly in the sampling bottles installed in the basement where the temperature was about 20°C. For the rest of the parameters except PO_4-P and NH_3-N, the t-test showed no significant (5%) difference between samples from Edmonton and samples from Whale Cove.

As the results of bacteriological analyses demonstrate, a wide range of indicator organisms can be expected in the raw bath and laundry wastewaters. The levels are sufficient to indicate a potential for fecal contamination of the bath and laundry wastewaters, which could in turn result in pathogenic contamination of these wastewaters. Communicable diseases can be transmitted by the pathogenic organisms in the wastewater.

In understanding the significance of the data presented here, it must be made clear that no members of the 3 groups of indicator organisms are normally pathogenic for adult humans. Their significance lies in the fact that, if they are present, other fecal-borne pathogenic bacteria (Salmonella, Shigella, etc.) or viruses(polio etc.) could also be present.

Chemical characteristics do not show good correlation between samples from Whale Cove and Alberta. The concentrations of phosphorus, and ammonia nitrogen are higher in samples from Whale Cove than in samples from Alberta. This variation in wastewater quality is as expected based on the reduced water usage, in most communities in the N.W.T. The wastewater produced are far more concentrated

than the wastewater produced in Alberta.

The important contaminants of concern in wastewater are suspended solids, biodegradable organics, pathogens and nutrients. Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged to the aquatic environment. Little is known about the effects that these suspended solids may have on the health of those who drink water that contains them. Nevertheless, it is possible that they may indirectly affect the quality of drinking water because bacteria and viruses from greywater can adsorb onto the suspended particles. By such means these materials may serve to concentrate, transport and protect bacteria and viruses. As seen from the results mean suspended solids concentration is found to be 294 mg/L (table IV-4), which is above the recommended limit of 15-30 mg/L in Alberta. Although this limit is for surface water discharge, it gives an indication of the degree of pollution in the greywater which could affect disinfection of this greywater.

In a wastewater of medium strength, about 75% of suspended solids are organic in nature (Metcalf & Eddy, 1979). Organic compounds are principally composed of proteins, carbohydrates, fats and oils. All organic substances contain carbon. Geometric mean of the organic content of greywater tested here as determined by TOC analysis is 210 mg/L. The recommended limit for sewage effluent discharge being 1 mg/L. If this greywater is

discharged to the environment untreated, extremely foul odors are apt to be produced by the decomposition of proteins and the microbial population would temporarily increase using protein and carbohydrates as nutrient source. Hendricks (1971) demonstrated that Shigella flexneri and a Salmonella sp. were capable of metabolising organic nutrients adsorbed to river sediment. Thus organic matter on the surface of the soil could act as a nutrient source for these organisms.

Concentration of inorganic substances such as nitrogen and phosphorus can also affect the environment, particularly if these constituents of wastewater are added to surface waters. Both nitrogen and phosphorus are essential to the growth of protista and plants. Although amounts of nitrogen present in greywater as NO_3 and NH_3 were found to be below recommended level,(NH_3 standard value is 10 -20 mg/L (Alberta Environment, 1977), phosphorus was present in very high concentrations. Phosphorus must be removed from greywater before the wastewater reaches surface waters, to prevent noxious algal blooms in surface waters. The presence of algae affects the value of the water as a water supply because they often cause taste and odor problems. Marginal amounts of chlorine enough for disinfection but not enough for oxidation, may intensify plankton odors and tastes. Major algal growths can also affect fish life in lakes.

In freshly polluted waters, most of the nitrogen is originally present in the form of organic(protein) nitrogen

and ammonia. As time progresses, the organic nitrogen is gradually converted to ammonia nitrogen and later on, if aerobic conditions are present, oxidation of ammonia to nitrites and nitrates occurs. As anticipated, the concentrations of ammonia nitrogen and nitrate nitrogen were quite low for samples from Edmonton since analyses were performed shortly after collection of samples. Samples from Whale Cove contained high amounts of NH_3-N possibly due to some oxidation of organic N, even though the samples were preserved prior to analysis. Nitrogen would be available from this greywater for algal and microbial growth. Even in samples with low amounts of NO_3-N and NH_3-N, as high as 14.5 mg/L Kjeldahl nitrogen was detected.

This characterization is based on a relatively limited basis of 28-32 samples during a comparatively short period of the year. In view of the great variations in concentration mentioned previously, it is, naturally doubtful whether the mean values calculated are really representative of the wastewater from the households and can be accorded a certain general validity. The values of most parameters calculated on the basis of this study lie within previously reported limits by other investigators. Even if a certain amount of caution is justified as far as the figures are concerned, it would seem, nevertheless, that one could, with some certainty, rely on the orders of magnitude which have been obtained from the analyses.

From the results obtained it is evident that special

attention must be paid to the greywater, since it carries a large pollutional load. This means that even when black water is eliminated this does not guarantee that the remaining greywater can be discharged without special treatment.

V. TREATABILITY EXPERIMENTS

The goals of greywater treatment are killing of disease-causing microorganisms, removal of harmful chemical substance and disagreeable colors and odors, and removal of solids. The following criteria were taken into consideration when proposing treatment processes that could be incorporated into an individual household:

1. the effluent quality produced;
2. the variability in effluent quality;
3. the minimization of operational and maintenance problems;
4. the economic feasibility with respect to installation, operation and maintenance; and
5. the total annual costs.

Considering the soil limitations, intermittent sand filtration of greywater was investigated as an alternative to subsurface disposal of household wastewater treatment. It was speculated that a substantial improvement in wastewater quality could be attained such that sand filtered effluent could be disinfected and discharged to surface waters.

From the information obtained from a literature survey on sand filtration, a bench scale treatment unit was designed, constructed and analyzed in order to evaluate the efficiency of filtration in treating greywater. Plate V-1 illustrates the apparatus used in treatment process and the arrangement of the processes. The study evaluated six wastewaters, the greywater influent, the sand filtered

Filter Column

Plate V-I

effluent, 3 chlorine disinfected effluent samples, and a lime disinfected effluent.

A. METHODOLOGY

Design of Treatment System

Two PVC columns of inside diameter 36 cm and length 1.2 m were filled with 61 cm of sand (approximate effective size of 0.4 mm) overlying 15 cm of supporting pea gravel. An underdrain of coarse gravel was placed beneath the pea gravel layer to distribute the flow over the surface area of the column during backwashing operations. Another layer of coarse gravel was placed above the layer of sand to distribute the flow of greywater over the surface of the column. The surface area of the filter was established so that the average daily loading rate was approximately 20 $mL/d/cm^2$. The distribution system consisted of a silicon rubber tubing 5 mm in diameter, leading from the vessel containing influent greywater to the sand filter via a pump regulated flow. The collection system of the sand filter consisted of a 5 cm plastic pipe at the bottom of the filter column leading to a collection vessel.

Operation

Only one filter column was used during operation of the filter system. The second column acted as a standby unit to be used if the column in service became clogged with solids or required other maintenance. A preliminary study was conducted from January 16, 1979 to January 24, 1979.

Greywater from the septic tank in Strathcona County was applied to the sand filter daily. 11.6 L of wastewater passed through the filter everyday over a span of 15 hours. This produced a hydraulic loading of 18 $mL/d/cm^2$.

Within 5 days water was leaking from the edge of the bottom surface of the column due to the weight of the sand in the column. The second column was put into operation with about 5.1 cm wooden blocks at the bottom of the column as an additional support. No further problems were noted in the operation of the filter column. This filter was operated for a period of 4 weeks. (February 26/79 to March 29/79.) The sand filter was to be operated until ponding above the sand occurred and reached the height of about 20 cm. However, during the period of operation (30 days), ponding did not occur.

Sampling and Analysis

Due to the remoteness of the site in N.W.T. and associated transportation problems, treatment studies were performed using greywater from a home in Edmonton. Wastewater was collected from a pipe connecting the kitchen sink, bathtub and washing machines. Since greywater was running through the sampling bottles during the time intervals between sampling, the composite samples were considered as representative. Samples were obtained every day and applied to the sand filter. The effluent from the filter was collected in a 20 L container.

Soon after collection, the effluent was disinfected

with three different concentrations of chlorine solution. Three 500 mL aliquots of effluent were dosed with 5, 10 and 15 mL of chlorine solution and mixed on a mixing machine at high speed for 30 minutes, after which residual chlorine analyses were performed. The chlorine solution was prepared by adding approximately 0.5 g of commercial domestic granular dry chlorine concentrate to 1 L of water. This solution was titrated with 0.025N sodium thiosulphate giving a chlorine concentration of 313.82 mg/L.

To determine "breakpoint" chlorination, several concentrations of chlorine were added to a sample and residual chlorine measured at those concentrations. The results are presented in figure V-1. Breakpoint chlorination was achieved at a chlorine dosage of about 3 mg/L. The three chlorine dosages used in this study were calculated to be 3, 6 and 9 mg/L.

Similarly, another 500 mL aliquot of effluent was dosed with 2 mL of lime slurry, containing 5 parts of boiled deionized water and 1 part of quicklime so that each mL contained nearly 0.2 g of lime. Contact time for lime disinfection was 30 minutes. This lime dosage of 800 mg/L increased the pH of the effluent to 12.

Total coliforms, fecal coliforms and fecal streptococci analyses were performed daily on all six samples, (i.e. influent greywater, sand filtered effluent, 3 chlorine disinfected effluent samples and the lime disinfected sample) as described in chapter IV under analytical methods.

Plot of Residual Chlorine versus chlorine dosage
demonstrating breakpoint phenomenon

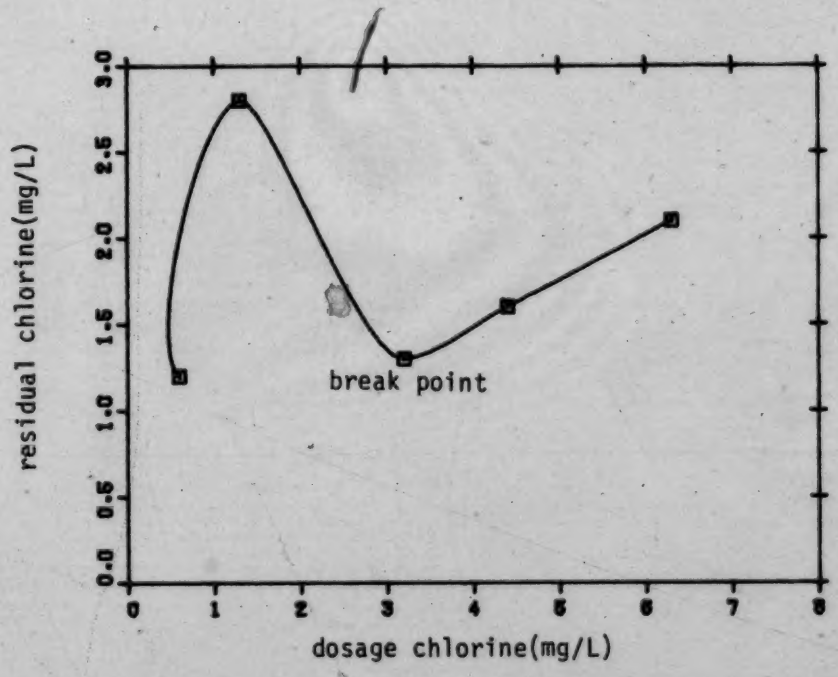


Fig. V-I

Before bacterial analyses on chlorinated samples, 0.5 mL of 100 g/L of sodium sulphite solution was added to 500 mL of sample to inactivate the residual chlorine. Sodium sulphite solution was prepared daily and sterilized by boiling.

pH of the samples were measured and suspended solids analyses were performed daily on influent and sand filtered effluent samples. Testing for total and ortho-phosphates, ammonia and nitrate nitrogen and total organic carbon was accomplished about every seventh day according to procedures described in chapter IV under analytical methods. Prior to the chemical analyses, the samples were refrigerated below $0^{0}C$. For TOC analyses, the samples were first acidified with a few drops of 1:1 hydrochloric acid. The samples were filtered for NO_3-N analyses. Residual chlorine was measured using iodometric method number 409A (APHA,1975).

B. RESULTS

The efficiency of treating the greywater with a sand filter is summarized in table V-1. The number of samples tested and the range of contaminant concentrations are also shown. As shown in table V-1, sand filtration produces a fairly high quality effluent, containing low concentrations of chemical/physical pollutants and indicator bacteria. Analyses of selected chemical/physical parameters on daily samples of effluent from the sand filter demonstrated significant reductions of TOC, suspended solids, total phosphorus and indicator organisms with mean effluent

TABLE V-I

Effluent Quality Data: Feb. 26 to March 29, 1979

Parameter	Number of Samples	Influent	Effluent	% Removal
Total coliforms (# per 100mL)	29	1.1×10^9	2.6×10^6	99.7
Fecal coliforms (# per 100mL)	29	2.0×10^6	3.4×10^3	99.8
Fecal strep. (# per 100mL)	29	3.4×10^3	1.2×10^2	96.4
TOC (mg/L)	29	142	34	76.2
S. solids (mg/L)	29	116	4.24	96
T-PO_4 (mg/L)	28	2.08	0.32	85
O-PO_4 (mg/L)	20	0.17	0.25	-47
NH_3 (mg/L)	27	0.04	0.06	-33
TKN (mg/L)	9	7.18	0.59	92

concentration of 34 mg/L for TOC, 4.24 mg/L for suspended solids, 0.32 mg/L for total phosphorus and 3.4 X 10^3 bacteria/100 mL for fecal coliforms. The pH of the effluent increased slightly above the pH of the influent.

Surface discharge recommendations for primary contact recreational waters for total and fecal coliforms are 1000/100 mL and 200/100 mL, respectively. Observation of the data shows the coliform level was substantially reduced by the sand filters, but effluent levels of coliforms remained higher than the current discharge recommendations. Disinfection of the sand filter effluent by chlorination reduced coliform levels below the recommended level, but average chlorine residuals of 1.5 mg/L, 3.2 mg/L and 5.2 mg/L were found after 30 minutes for the 3, 6 and 9 mg/L chlorine dosages, respectively.

Although lime disinfection is effective in removal of fecal coliforms and fecal streptoccoci, the mean total coliform count was found to be 1218/100 mL, i.e. above the recommended standard of 1000/100 mL.

To check for regrowth of bacteria after dechlorination, bacteriological analysis were performed daily on chlorinated samples stored at room temperature from a period of 10 days from March 20, 1979 to March 29, 1979. The chlorinated sample contained <100 total coliforms, fecal coliforms and fecal streptococci per 100 mL for all three chlorine dosages. As shown in table V-2, no regrowth of bacteria is observed in samples dosed with 3 and 6 mg/L. However, the

TABLE V-2

Bacteria Regrowth Analysis: March 20 to March 29, 1979

Day	# Total coliforms/100mL for Sample dosed with 9 mg/L chlorine
20/3	100
22/3	100
23/3	1200
24/3	6200
26/3	2500
27/3	2100
28/3	3100
29/3	100

1) All samples dosed with 3, 6 mg/L chlorine showed no regrowth.

2) No regrowth of fecal coliforms & fecal strep.

sample dosed with 9 mg/L chlorine showed regrowth of total coliform organisms after 2 days. No general trend was observed in the amount of regrowth with time. Most likely regrowth occured due to contamination of sample, since regrowth was observed for total coliform only.

Figures V-2 to V-9 illustrate the increase in treatment efficiency with time, particularly in the case of fecal coliforms. It should be remembered here that the points in the figure indicating 100 coliforms per 100 mL represent the value <100 coliforms per 100 mL i.e. the value below detection limit. No fecal streptococci colonies were detected in one mL sample for most cases. This is shown in Fig. V-4 as <100 coliforms per 100 mL.

Suspended solids are almost completed removed from the greywater as observed from Fig V-6. A 96% removal is attained when percentage removal is calculated using geometric means. The general trend of increased efficiency with time exists for TOC and total phosphates though to a lesser extent. However, in the case of ortho phosphates, the plot of effluent data parallels the one of influent data showing there is virtually no removal of ortho phosphates. In fact, some of the effluent samples have a higher concentration than the influent. The percentage reroval calculations, based on geometric means show a slight increase in both $O\text{-}PO_4$ and $NH_3\text{-}N$.

The increase in NH_3-N concentration in the effluent is quite noticeable in Figure V-9. It is also interesting to

Influent Effluent Plot for Total Coliform

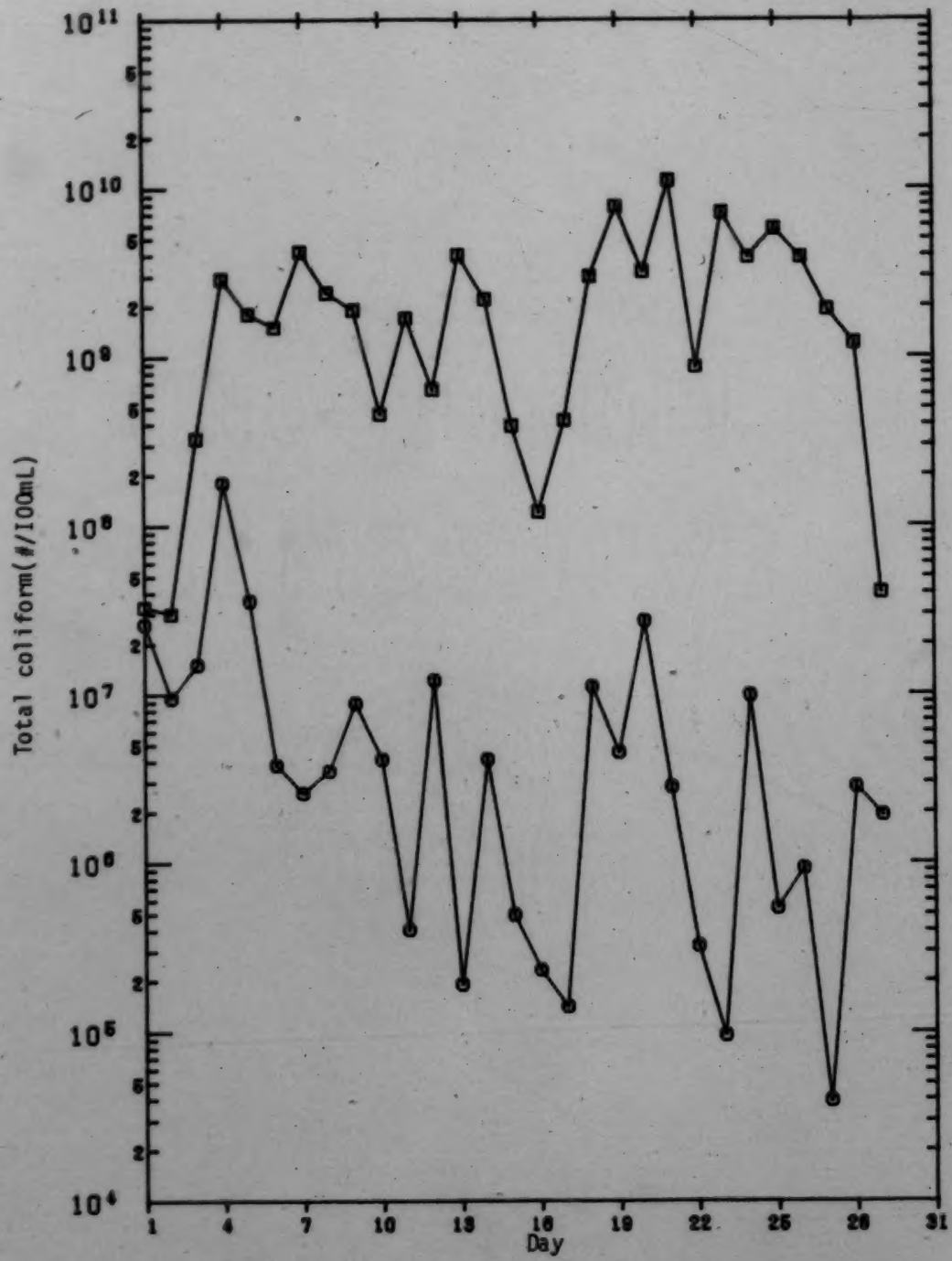


Fig. V-2

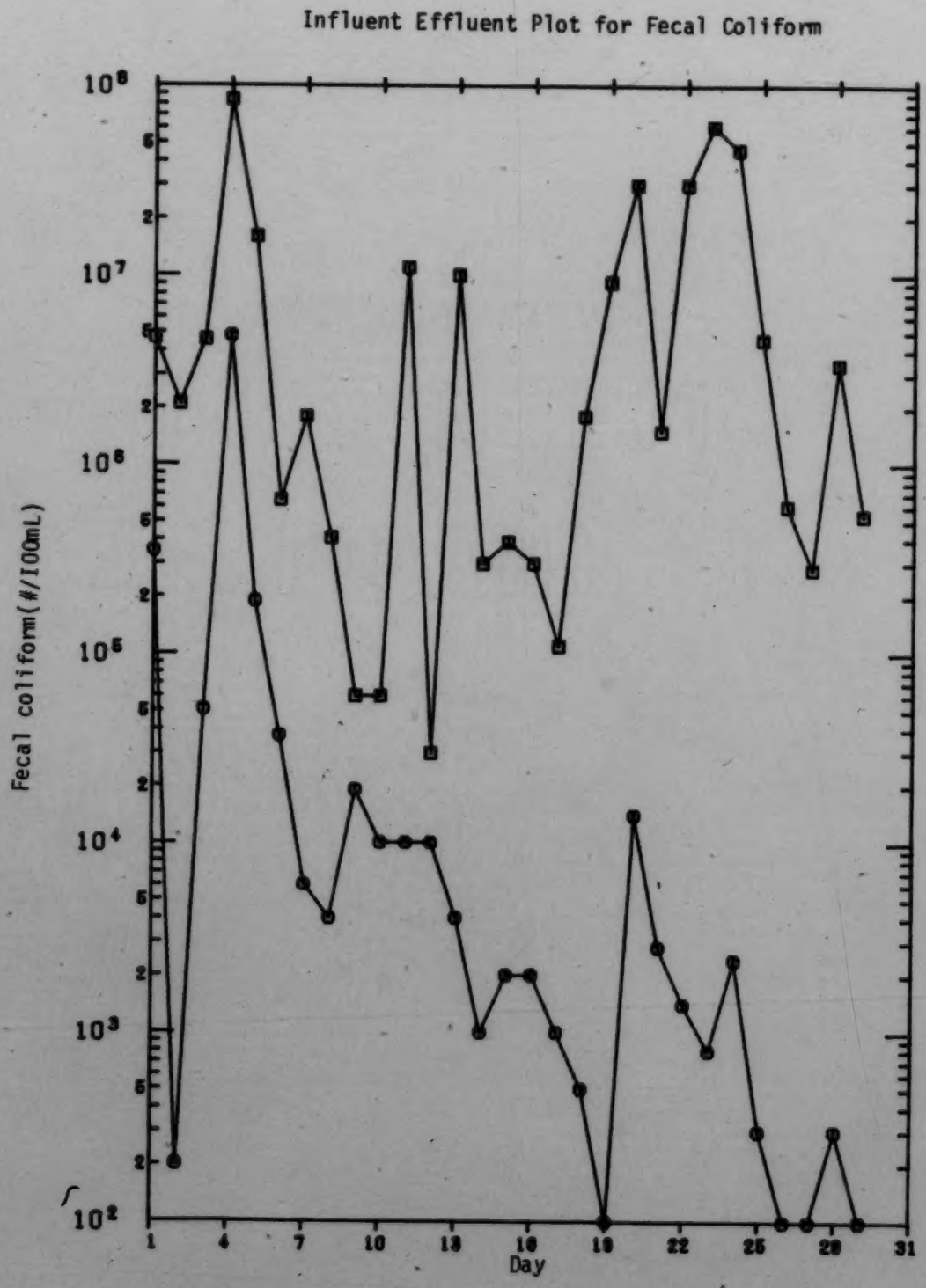

Influent Effluent Plot for Fecal Coliform
Fecal coliform(#/100mL)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
5
2
1
4
7
10
13
16
19
22
25
28
31
Day

Fig. V-3

Influent Effluent Plot for Fecal Strep.

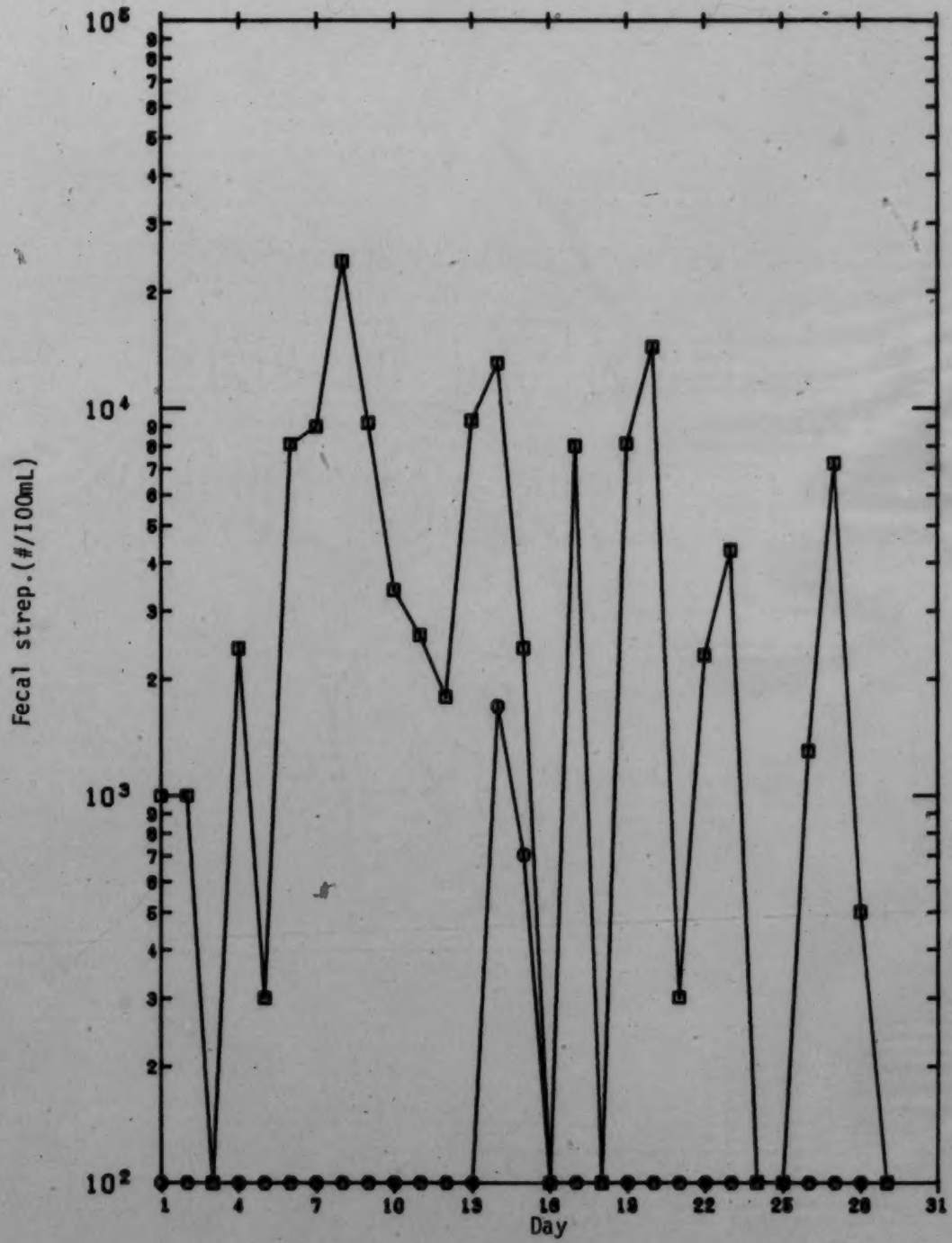


Fig. V-4

Influent Effluent Plot for TOC

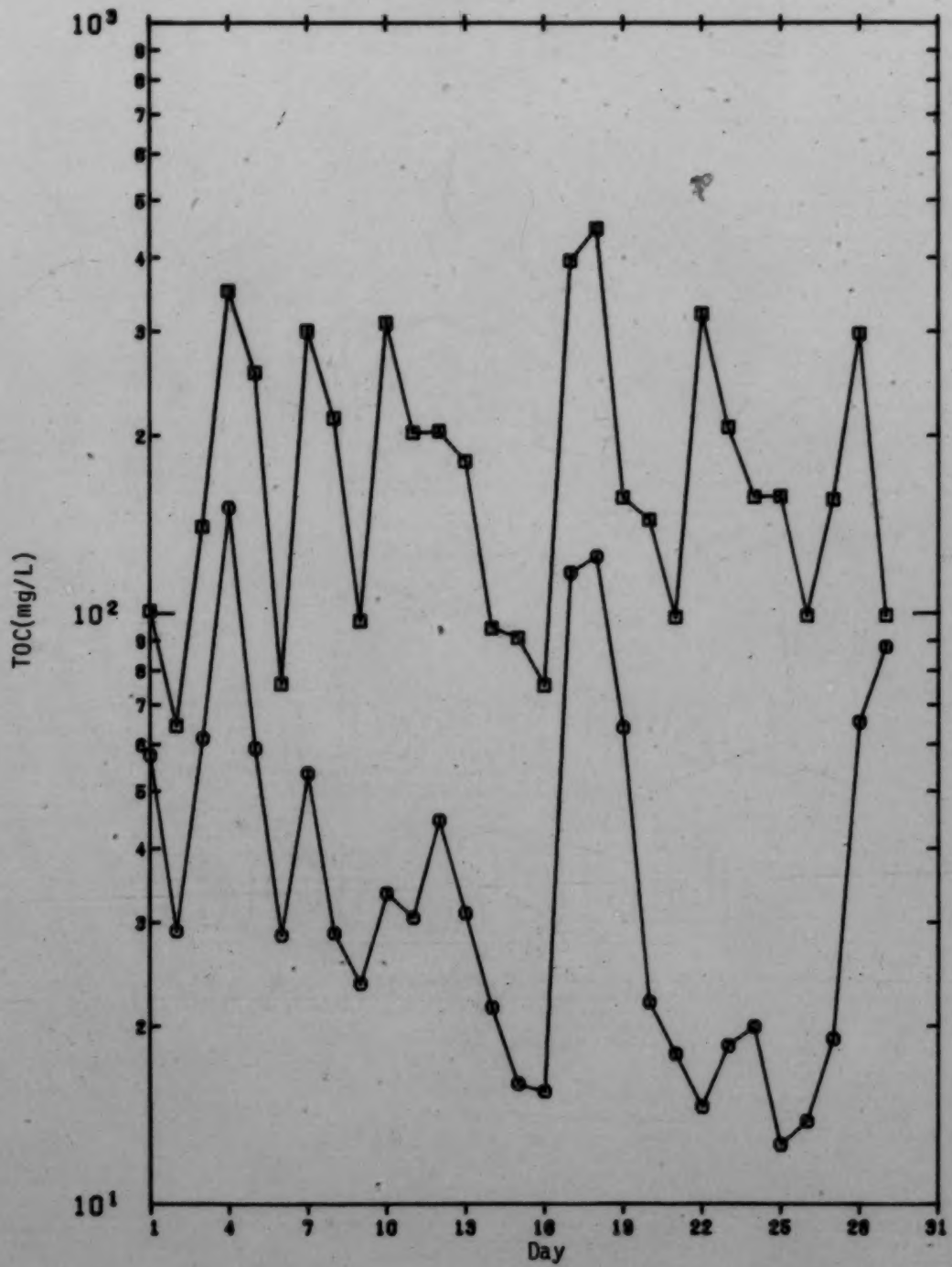


Fig. V-5

Influent Effluent Plot for S. Solids

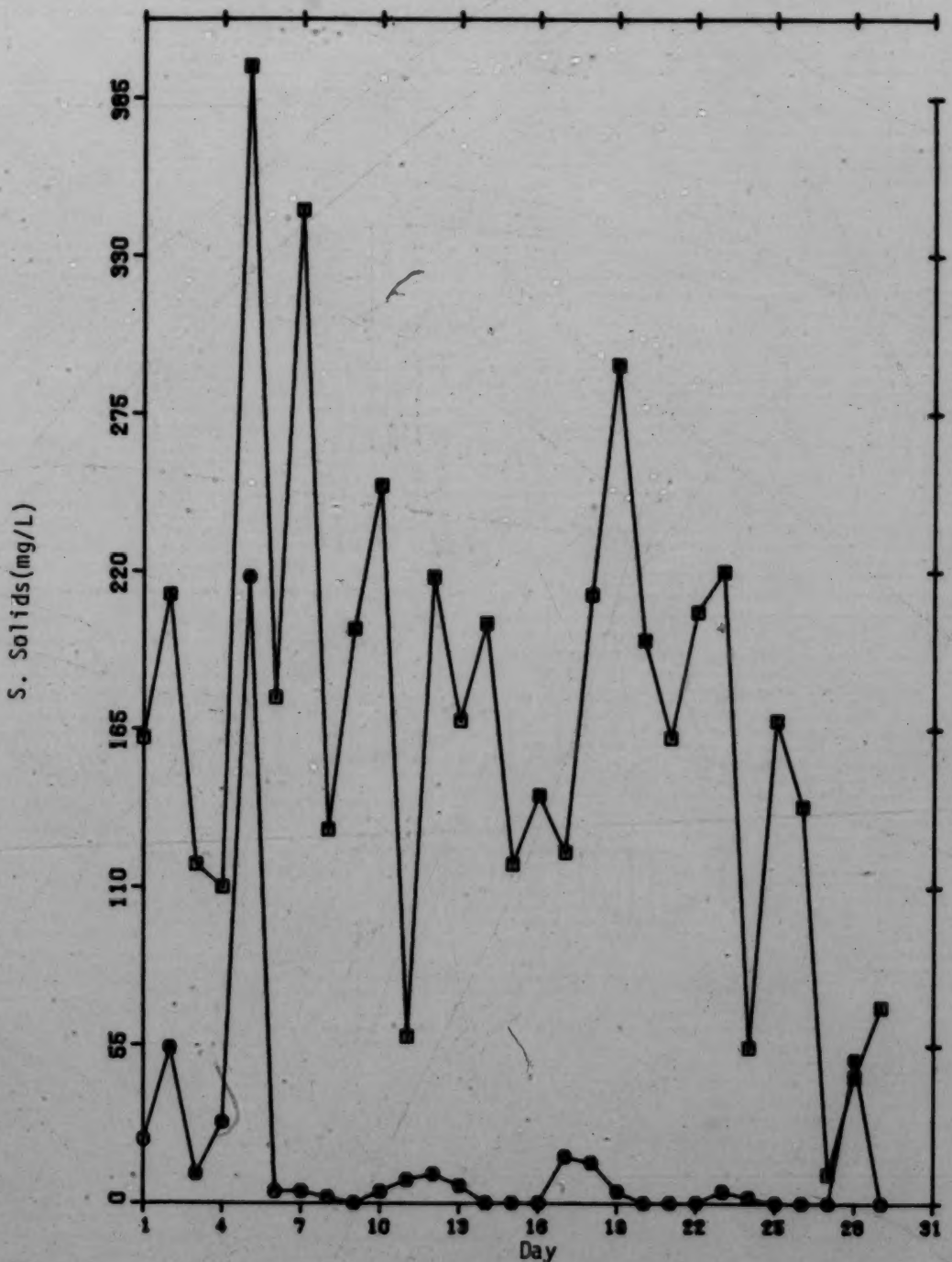


Fig. V-6

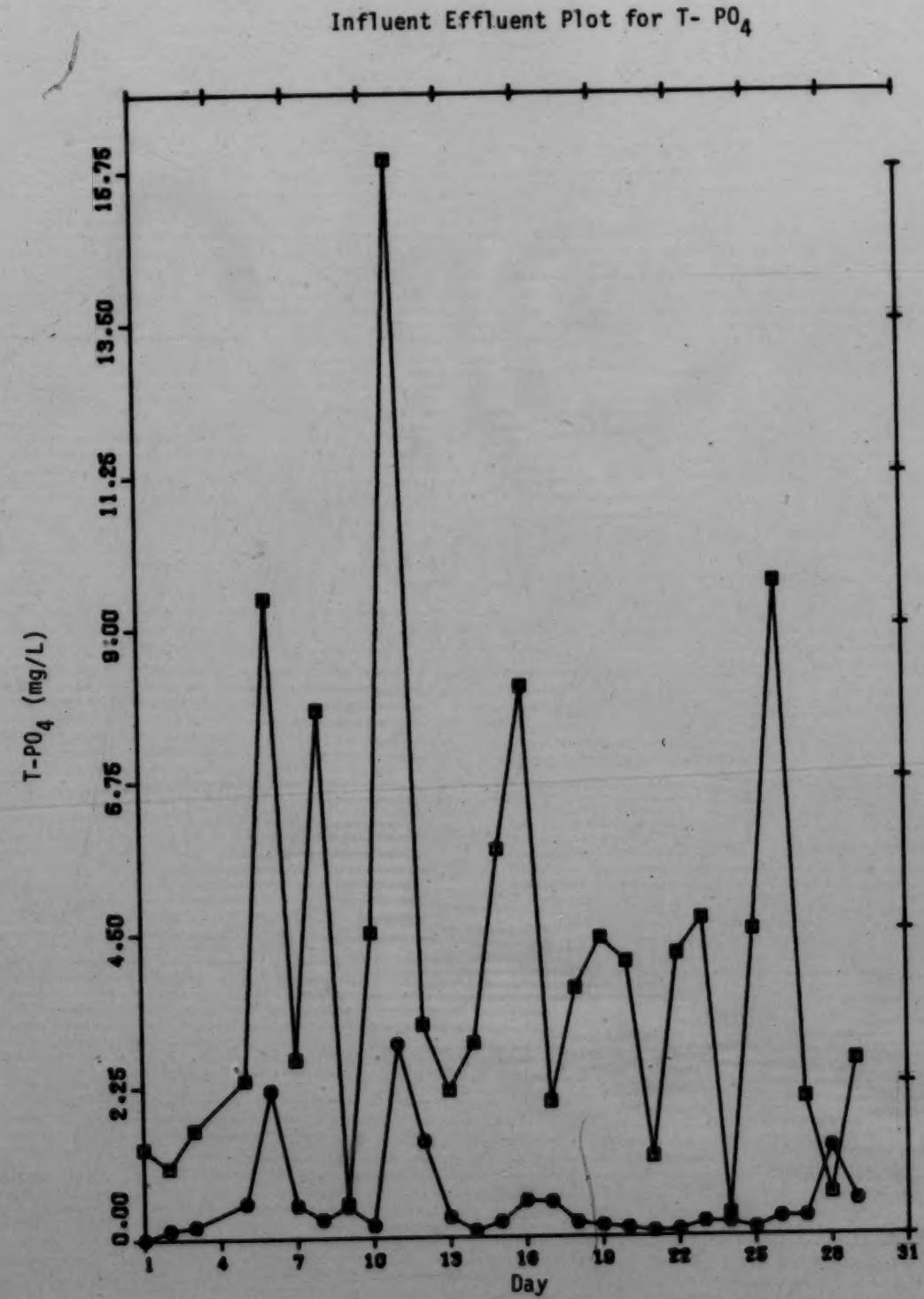

Influent Effluent Plot for T- PO4
T-PO4 (mg/L)
0.00
2.25
4.50
6.75
9.00
11.25
13.50
15.75
1
4
7
10
13
16
19
22
25
28
31
Day

Fig. V-7

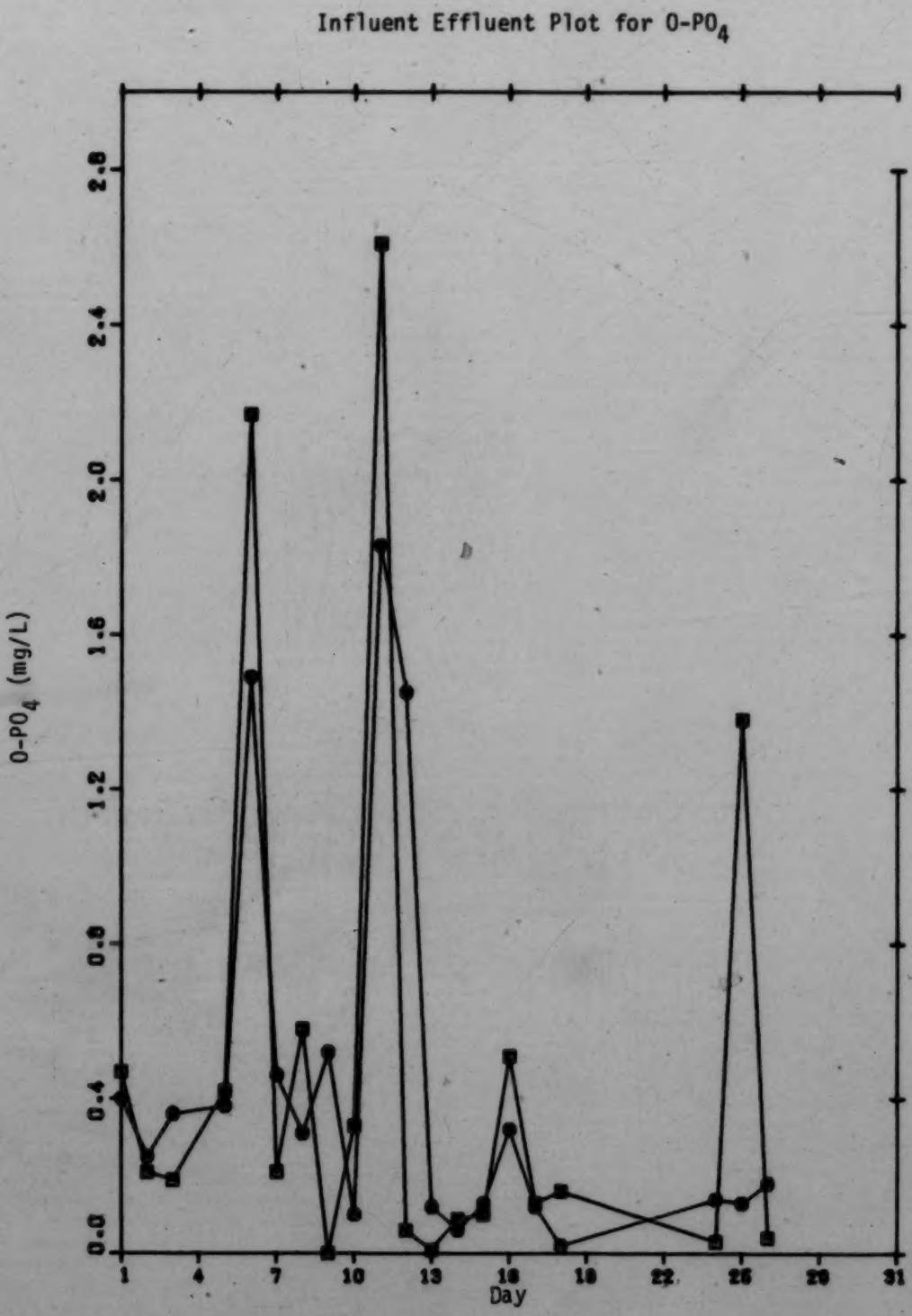

Influent Effluent Plot for O-PO4
O-PO4 (mg/L)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
1
4
7
10
13
16
19
22
25
28
31
Day

Fig. V-8

Influent Effluent Plot for Ammonia

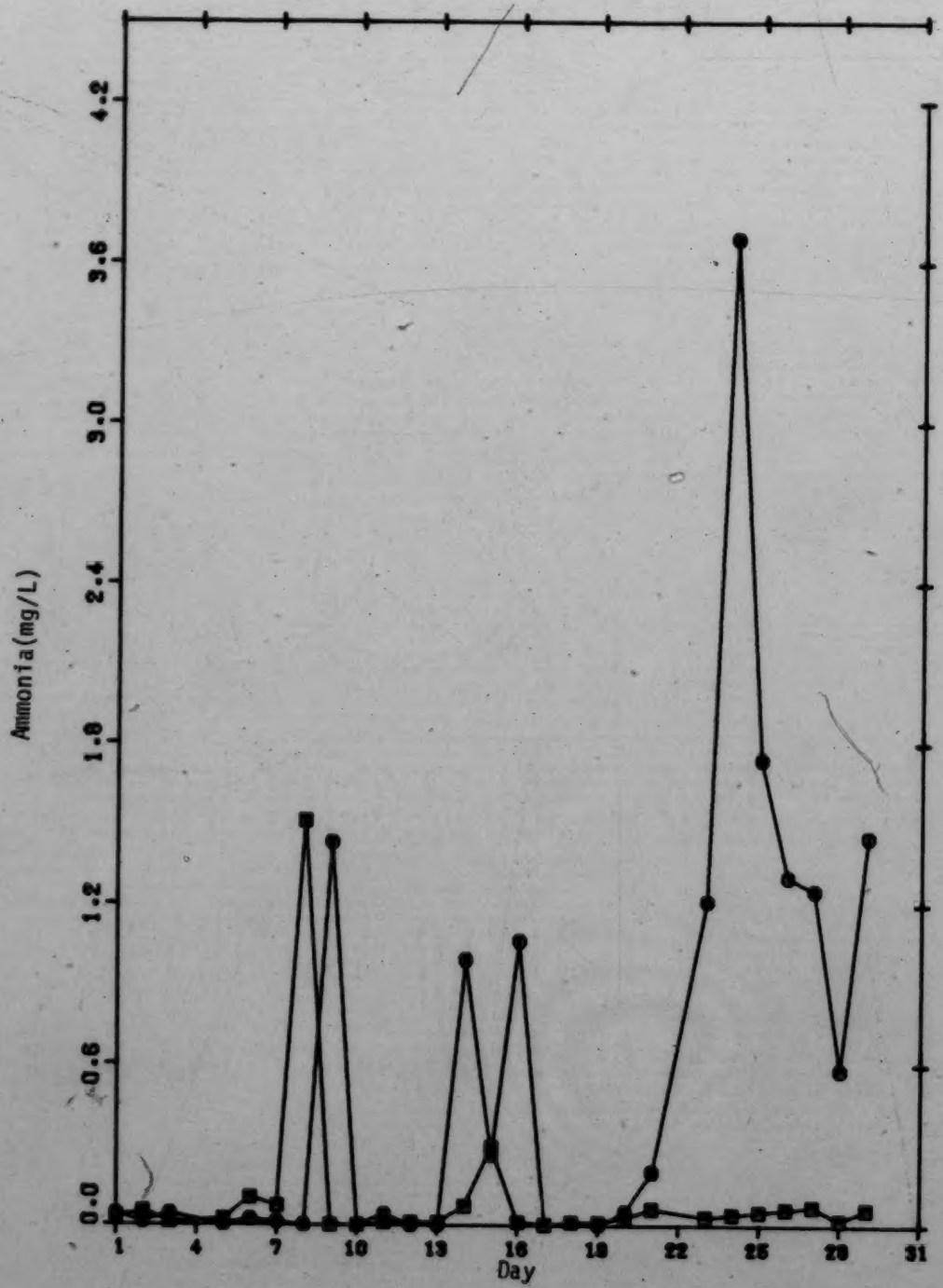


Fig. V-9

note that for the first seven days, there is negligible amounts of ammonia present in both the influent and the effluent samples. Near the end of the experimental period, the NH_3 concentrations in the effluent samples are quite high compared to the influent concentrations which are still very low.

To check the source of this nitrogen in the effluent, total Kjeldahl nitrogen was determined in 9 samples. The results are provided in table V-1. The mean concentration was 7.18 mg/L in the influent, 92% of this was removed in passing through the filter column. The increase in NH_3-N in the effluent is most likely due to the oxidation of organic nitrogen taking place in the sand filter column.

Three different concentrations of chlorine and one concentration of lime were used to disinfect the effluent from the filter column. To test whether there was any difference between the four treatments, a one way analysis of variance test was performed. In this case, there was evidence of a difference between the treatment methods, at a 5% significance level. It was concluded, from computations of least significant difference that there was no difference between the three dosages of chlorine used. However, treatment with lime was significantly different from the three chlorine treatments, in that it was not as effective as the others.

C. DISCUSSION

This research has shown that sand filtration is effective in treating household greywater. The results show that a sand filter of an effective grain size of about 0.4 mm, is able to reduce the fecal coliforms from 2.0×10^6 to 3.4×10^3 per 100 mL of greywater. The concentration of total coliforms was reduced from 1.1×10^9 to 2.6×10^6 per 100 mL at the same time.

The straining of bacteria at the soil surface is possibly the main mechanism involved in removal of bacteria by soil. When suspended particles, including bacteria, accumulate on the soil surface, as water passes through the soil these particles themselves become the filter (Krone et al., 1958). Such a filter is capable of removing even finer particles. Thus, the removal efficiency would increase with time, as seen from the results in Figures V-2, V-3 and V-6.

Two of the chemical parameters that do not follow the general trend of increased removal with time, are NH_3-N and O-PO_4. The increase in concentration of NH_3-N is more pronounced than the increase in O-PO_4 concentration in the effluent.

Hydrolysis of complex phosphates to ortho phosphates and the decomposition of organic nitrogen into NH_3, during the passage of greywater through the column could account for the above observation. Nitrogen and phosphorus are both essential nutrients for bacterial growth. As organisms accumulate in the column, there is a possibility of bacteria

metabolizing organic nitrogen and phosphates. Most organisms hydrolyze phosphates into soluble phosphates before they can incorporate them into their cellular consitiuents. Thus, besides using the available orhto phosphates the organisms convert some of the complex phosphates to ortho phosphates, thus either increasing or maintaining the level of soluble phosphates in the sand filtered effluent.

Similarly, protein, nucleic acids and some other organic nitrogenous compounds are hydrolyzed to amino acids and similar compounds when they are metabolized by microorganisms. Under anaerobic conditions some of the amino acids are converted to offensive odor producing amines and related products. In the presence of oxygen the amines are oxidized with the liberation of ammonia.

The filter column is essentially an aerobic condition. Thus, the amino acids are oxidized to form ammonia.

Since in most cases the volumes of wastewater are small and the possible dilution by receiving waters is large, it is mainly health protection that is a concern rather than general degradation of water quality.

Due to a small hydraulic loading (18 mL/d/cm^2) over 99 % removal of total and fecal coliform organism from household wastewater was achieved. However, the number of organisms was still higher than the recommended standard, thus requiring disinfection prior to surface discharge. Of the two disinfectants studied in this experiment, chlorine is found to be more efficient than lime. Besides being a

less effective disinfectant, there are problems of the final sludge disposal and pH adjustment of effluent after lime disinfection. There is no significant difference in the numbers of coliforms remaining when the three different dosages of chlorine are applied to the sand-filter effluent. The values of the three dosages of chlorine were above breakpoint. Chlorine has a good record of being a satisfactory wastewater disinfectant for public health protection against waterborne diseases. There are, however, associated problems with current chlorination practices. As discussed in chapter II, the use of chloriration is sometimes discouraged due to its adverse effects. However, in this study, disinfection by chlorination was found to be more suitable method of the two. A very low dosage (3 mg/L) is required for effective disinfection of greywater, leaving a mean residual of 1.46 mg/L after a 30 minute contact period. The recommended dosage for activated sludge plant effluent is 10 mg/L and the Alberta Government Standard for residual chlorine is 2 mg/L.

Among all the alternate disinfection techniques, at present, hypochlorite appears to be the most satisfactory. It can be easily transported, is simple and safe to use. Since residual levels are below recommended standard, the effluent is relatively safe for surface discharge.

A laboratory study showed that total coliforms were capable of regrowth after dechlorination of sand filtered chlorinated effluent. However, no regrowth of fecal coliform

or fecal streptococci was observed suggesting a different potential for regrowth for different groups of coliform organisms.

As observed by Shuval et al. (1973), an inverse relation between the occurrence of regrowth and the number of bacteria surviving chlorination was noted in this study. However, a direct relationship was observed between occurrence of regrowth and the amount of residual chlorine, contrary to the results obtained by Shuval et al. (1973). The former relationship may be due to the general absence of competitive microflora in the effluent treated with high chlorine dosage. The unexpected occurrence of regrowth in sample chlorinated with 9 mg/L chlorine cannot be explained with the limited number of data. To fully understand the regrowth phenomenon a detailed study should be undertaken.

Although the regrowth test showed no organisms in a 10 mL sample after chlorination, regrowth nevertheless occurred, indicating that some bacteria were present in the chlorinated effluent. Testing larger volumes of effluent of 200-500 mL might overcome this apparent error.

Since different coliform groups showed different capacities of regrowth, one cannot assume that when coliforms regrow, the pathogens are regrowing as well. In the absence of clear evidence that pathogens behave in a similar manner to total coliforms, absence of regrowth of fecal coliforms can be considered as indication of absence of regrowth of pathogens.

It is known that viruses cannot multiply outside the living host and to the extent that their numbers are reduced by chlorination no regrowth can occur.

No pH adjustment is required for the sand filtered chlorinated effluent, since the treated effluent is neutral. Thus, it can be considered safe for surface discharge.

VI. SUMMARY AND CONCLUSION

Domestic sewage can contain the complete renge of pathogenic organisms such as agents causing cholera, typhoid fever, bacillary dysentery as well as enteric viruses and parasites.

The aim of this investigation was to study the quantity and nature of household wastewater, i.e. greywater from the dwellings in an isolated northern community and to determine whether this greywater could potentially be a public health hazard. The results were to provide a basis for choosing suitable treatment measures.

The data generated in analysis of characteristics of greywater from Whale Cove is summarized in table IV-4. The daily pollutant contributions can vary considerably at a given home as seen from Figures A1-A18, and also between homes due to different living habits. A log normal distribution was demonstrated for all the parameters measured in this study. The values obtained for most parameters from the two sources of greywater(Edmonton and Whale Cove) did not differ significantly, except for NH_3, PO_4 and total coliforms. These differences were largely due to differences in wateruse.

The microbiological content of greywater is of prime importance. As discussed previously, the presence of an individual who is shedding pathogens in a household wastewater will result in pathogens appearing in the wastewater stream. Although no work was done to actually

delineate the pathogenic characteristics of greywater, the values presented for coliform organisms demonstrate that a wide range of indicator organisms can be expected in the bath and laundry wastewaters. The levels are sufficient to indicate a potential for fecal contamination of the bath and laundry wastewaters, which could in turn result in pathogenic contamination of these wastewaters. Health statistics show that many of the diseases mentioned are endemic in the communities in the N.W.T. Hence, it is possible that such pathogens will occur in greywater.

The findings of this investigation with respect to chemical characteristics of greywater suggest that sufficient nutrients are available for growth and maintenance of a microbial population in this wastewater, and that spring runoff containing this wastewater could contaminate drinking water sources. These results indicate the necessity for wastewater treatmert to protect public health.

Since central sewerage and water distribution systems do not exist in most northern communities, and many areas are simply unsuitable for on-site treatment and disposal by the septic tank system, an intermittent sand filtration with surface disposal of effluent was evaluated. The inability to meet the bacterial standards does not eliminate sand filtration as a potential treatment mechanism, but indicates that filtration alone is not adequate for removal of bacteria from household greywater. Disinfection following

filtration has been found effective in producing an acceptable effluent quality, under laboratory conditions.

However, these results were not conclusive evidence of the feasibility of operating the treatment process under conditions similar to those found in N.W.T. Three important factors which should be further assessed are the possible occurrence of clogging of the filter columns, economics of the system, and, probably more important, the operation and maintainance requirements.

Intermittent sand filtration and chlorination appear to be a practical solution for prevention of adverse effects of greywater , particularly if piped water distribution to homes is anticipated in the near future.

VII. RECOMMENDATIONS

1. In an attempt to better identify the potential for contamination of household greywater by pathogenic bacteria and viruses, greywater should be further characterized for pathogens. Siegrist (1977) found certain enterobacteriaciae in greywater indicating possible fecal contamination.
2. Because of certain limitations of the coliform group as general indicators of non-enteric pathogen contamination, other indicators such as Pseudomonas and Staphlococcus should be assessed. In the literature there has been some indication that P. aeruginosa is present in greywater. It is recommended that in addition to coliform tests, qualitative tests be conducted to determine presence of P. aeruginosa.
3. Since, at present, there is a lack of convincing evidence that water sources are the cause of waterborne diseases in the N.W.T., it is recommended that epidemiological studies of water quality and health be performed in addition to acquiring better reporting of outbreaks of waterborne disease.
4. Excessive use of chlorine in water treatment may result in the formation of several compounds that are known carcinogens for animals and suspected carcinogens for humans. There is a possibility that disinfection with a chlorine dosage of less than 3 mg/L could be effective in removing microorganisms. It is recommended that the

effect of chlorination below "breakpoint" be assessed, even though carcinogenic effect of chlorination is not likely to pose a problem at present in the N.W.T.

5. Since characteristics of greywater are affected by temperature, particularly microbiological characteristic, greywater should be examined under winter conditions as experienced in N.W.T.
6. It is known that bacteria and viruses can survive freezing temperatures, this should be investigated by analysing spring thaw samples of greywater.
7. A close monitoring of the pattern of wastewater flow and the volume of wastewater produced at homes in the communities in N.W.T. is recommended to generate the necessary data to design a complete household treatment system.

As a final general recommendation, it is felt that an extensive field investigation should be conducted on characterization and treatment system in order to assess the suitability of sand filtration- chlorination under conditions found in N.W.T.

GLOSSARY

Endemic - peculiar to a certain region or people; said of a disease that occurs more or less constantly in any particular locality.

Endocarditis - Inflammation of the endocardium or lining membrane of the heart cavities and its valves.

Endocardium - The membrane lining the interior of the heart.

Enterocolitis - Inflammation of small intestine and colon.

Epidemic - of diseases, occuring or tending to occur in extensive outbreaks, or in unusually high incidence at certain times and places.

Epidemiology - The study of occurrence and distribution of disease; usually restricted to epidemic and endemic, but sometimes broadened to include all types of disease.

Fulminant - Sudden, severe, intense and rapid in course. (adj. fulminating)

Honey bags - plastic bags used for toilet wastes.

Mastoid cell - One of the compartments in the mastoid part of the temporal bone. (i.e. bone forming part of the skull)

Mastoiditis - Inflammation of the mastoid cells.

Meningitis - Any inflammation of the membranes of the brain or spinal cord.

MPN - Statistical estimate of a bacterial population through the use of dilution and multiple tube inoculations.

Osteomyelitis - Inflammation of the marrow and hard tissue of bone, usually caused by a bacterial infection.

Pericarditis - Inflammation of the pericardium.

Pericardium - The closed membranous sac enveloping the heart.

Pustule - A small, circumscribed elevation of the skin containing pus.

Pyelonephritis - The disease process from the immediate and late effects of bacterial and other infections of the kidney.

Sequela - An abnormal condition following a disease upon which it is directly or indirectly dependent.

Thrombophlebitis - Inflammation of a vein associated with thrombosis.

Thrombosis - The formation of a clot of blood formed during life within the heart or blood vessels.

Virion - The complete, mature virus particle, identical to the infectious unit.

Virulent - Infectious, noxious.

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APPENDIX

TABLE A-I

CHARACTERISTIC OF GREY WATER FROM WHALE COVE
:AUG 21 TO SEPT 16, 1978

DAY	TOTAL COLIFORM #/100 mL	FECAL COLIFORM #/100 mL	FECAL STREP. #/100 mL	TOC mg/L	S. SOLIDS mg/L	T-PO_4 mg/L	O-PO_4 mg/L	NO_3-N mg/L	NH_3-N mg/L
1.	$1.6X10^8$	$1.2X10^7$	$8.0X10^5$	1.0	1.0	4.50	2.41	0.078	0.01
2.	$2.1X10^7$	$3.5X10^6$	$5.9X10^4$	345.0	902.0	27.70	3.36	0.110	0.65
3.	$2.2X10^8$	$5.0X10^6$	$2.9X10^5$	416.0	458.0	16.10	4.27	0.043	1.41
4.	$3.9X10^7$	$1.8X10^7$	$3.0X10^6$	1420.0	1372.0	14.00	7.57	0.074	0.42
5.	$7.0X10^7$	$1.3X10^7$	$1.2X10^5$	305.0	248.0	10.30	4.03	0.043	1.25
6.	$8.3X10^7$	$1.1X10^7$	$3.0X10^3$	300.0	6.5	1.23	0.02	3.630	0.01
7.	$6.3X10^7$	$3.2X10^5$	$2.3X10^3$	4230.0	1982.0	13.80	7.79	0.014	11.49
8.	$2.0X10^6$	$4.0X10^5$	$6.0X10^2$	47.5	354.0	9.20	5.68	0.008	2.09
9.	$1.0X10^6$	$1.0X10^4$	$6.1X10^3$	745.0	280.0	5.80	1.63	0.042	1.47
10.	$2.0X10^7$	$3.8X10^6$	$1.7X10^4$	263.0	138.0	14.00	0.01	0.010	2.08
11.	$4.2X10^7$	$3.6X10^6$	$1.0X10^5$	121.0	450.0	6.40	0.28	0.008	0.31
12.	$3.4X10^5$	$3.0X10^4$	$1.0X10^3$	956.0	1108.0	11.20	0.01	0.001	0.01
13.	$8.1X10^6$	$5.0X10^6$	$7.1X10^5$	1910.0	5007.0	103.00	46.70	0.500	70.80
14.	$5.4X10^7$	$1.8X10^6$	$3.7X10^3$	295.0	200.0	14.20	0.28	0.003	1.42
15.	$8.0X10^6$	$3.5X10^6$	$1.0X10^2$	115.0	64.0	11.60	6.06	0.006	2.34
16.	$5.4X10^7$	$1.5X10^7$	$5.9X10^3$	94.0	632.0	17.00	0.65	0.003	0.93

TABLE A-I

CHARACTERISTIC OF GREYWATER FROM WHALE COVE
AUG. 21 TO SEPT. 16, 1978

DAY	TOTAL COLIFORM #/100 mL	FECAL COLIFORM #/100 mL	FECAL STREP. #/100 mL	TOC mg/L	S. SOLIDS mg/L	T-PO_4 mg/L	O-PO_4 mg/L	NO_3-N mg/L	NH_3-N mg/L
17.	$6.2X10^7$	$1.3X10^6$	$5.1X10^3$	145.0	318.0	5.50	1.85	0.001	0.89
18.	$6.0X10^5$	$1.0X10^4$	$3.8X10^5$	1060.0	1374.0	6.50	4.40	0.018	10.48
19.	$5.0X10^7$	$1.0X10^7$	$4.0X10^2$	222.0	318.0	4.20	0.53	0.032	1.63
20.	$1.7X10^7$	$1.7X10^6$	$3.9X10^3$	446.0	636.0	21.50	19.30	0.024	1.90
21.	$3.5X10^7$	$2.0X10^6$	$1.0X10^2$	221.0	168.0	13.90	0.01	0.008	1.45
22.	$1.8X10^7$	$6.4X10^6$	$1.0X10^2$	272.0	1200.0	15.60	0.45	0.013	2.21
23.	$8.2X10^7$	$7.7X10^6$	$1.0X10^2$	435.0	1424.0	14.80	5.01	0.001	0.35
24.	$2.4X10^7$	$1.2X10^6$	$1.0X10^2$	145.0	128.0	6.20	3.61	0.015	3.34
25.	$2.4X10^6$	$4.4X10^5$	$3.2X10^3$	72.0	228.0	2.50	1.02	0.038	1.38
26.	$4.4X10^6$	$6.0X10^5$	$4.0X10^3$	113.0	368.0	7.90	1.99	0.100	3.33
27.	$1.5X10^6$	$4.9X10^5$	$1.0X10^4$	47.0	138.0	4.00	2.13	0.032	3.73
28.	$6.0X10^6$	$1.4X10^6$	$9.0X10^2$	362.0	544.0	10.00	1.04	0.024	1.93
29.	$1.5X10^7$	$2.1X10^6$	$3.9X10^3$	66.0	178.0	4.00	0.85	0.022	0.86
30.	$2.5X10^7$	$1.7X10^6$	$2.0X10^2$	62.0	290.0	7.70	2.46	0.017	3.40
31.	$1.4X10^7$	$1.2X10^6$	$6.0X10^2$	37.0	292.0	5.00	0.01	0.020	0.14
32.	$1.2X10^7$	$2.4X10^6$	$1.0X10^2$	261.0	342.0	9.00	1.50	0.012	3.56

TABLE A-2

Characteristics of Grey Water from Strathcona County: Jan. 16 - Jan. 24, 1979

Day	Total coliform	Fecal coliform	Fecal strep.	TOC	S. solids	$T\text{-}PO_4$	$O\text{-}PO_4$	NH_3
1	3.6×10^5	7.1×10^5	4.1×10^5	87	256	2.79	2.94	-
2	3.6×10^7	5.2×10^6	100	330.5	834	6.66	4.45	0.03
3	2.8×10^6	5.6×10^5	100	80.0	192	3.2	4.69	0.02
4	1.2×10^7	1.2×10^6	100	93.4	232	3.25	2.74	0.02
5	8.1×10^6	1.5×10^6	1400	79.4	86	3.23	2.34	0.20
6	5.0×10^7	4.9×10^6	5900	117.6	280	3.36	2.71	0.52
7	1.1×10^8	4.1×10^6	-	-	-	-	-	-

TABLE A-3

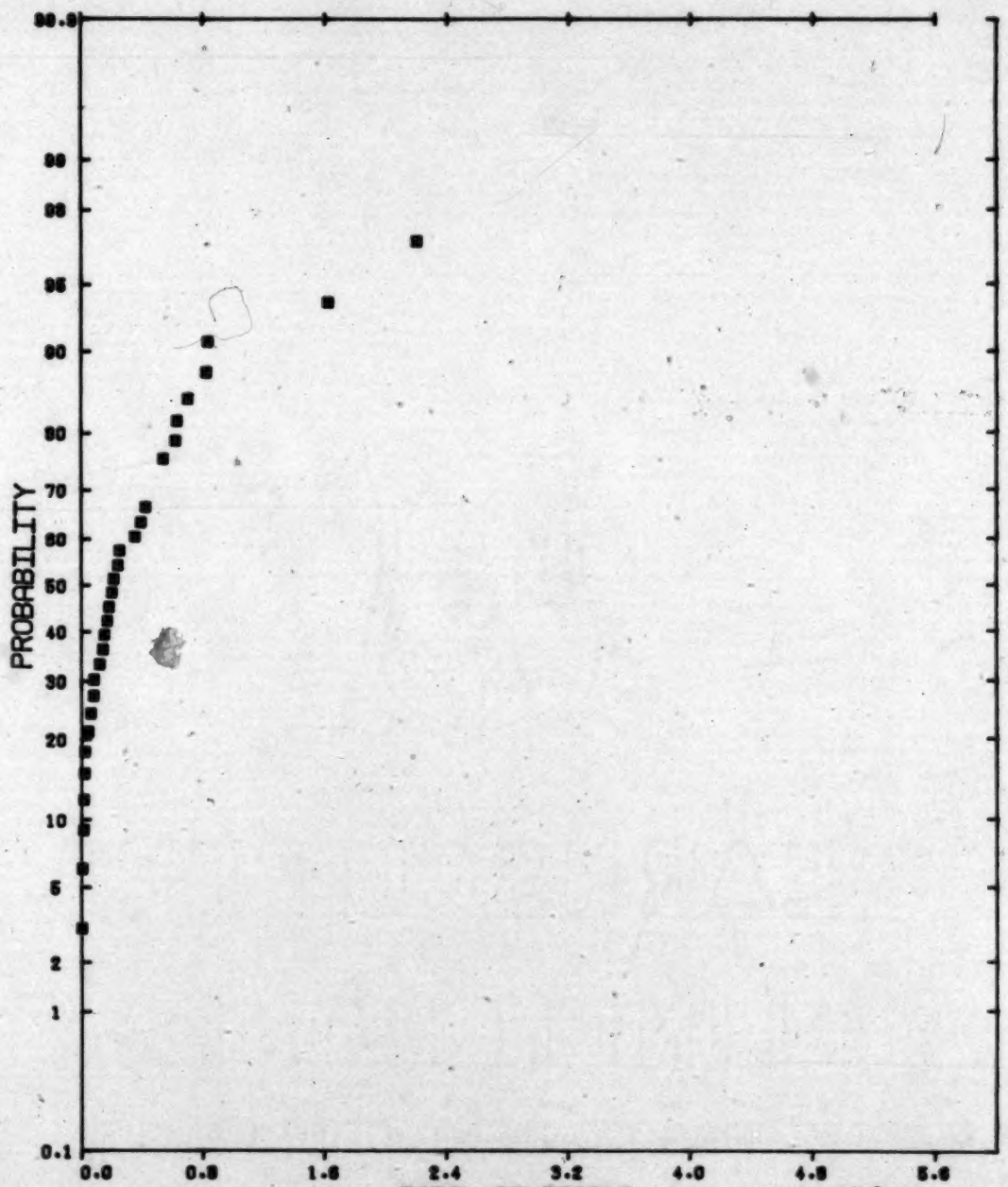
Microbiological Characteristics of Grey Water from Strathcona County: July 6 - July 14, 1978

Day	Total coliform	Fecal coliform	Fecal strep.
1	5.1×10^6	4.0×10^6	6.3×10^4
2	10×10^6	-	5.0×10^4
3	8.3×10^6	-	2.8×10^4
4	9.4×10^6	3.1×10^6	6.7×10^4
5	1.6×10^7	1.1×10^7	1.1×10^5
6	9.3×10^6	2.2×10^6	1.6×10^4
7	6.7×10^6	4.7×10^6	1.9×10^4

TABLE A-4

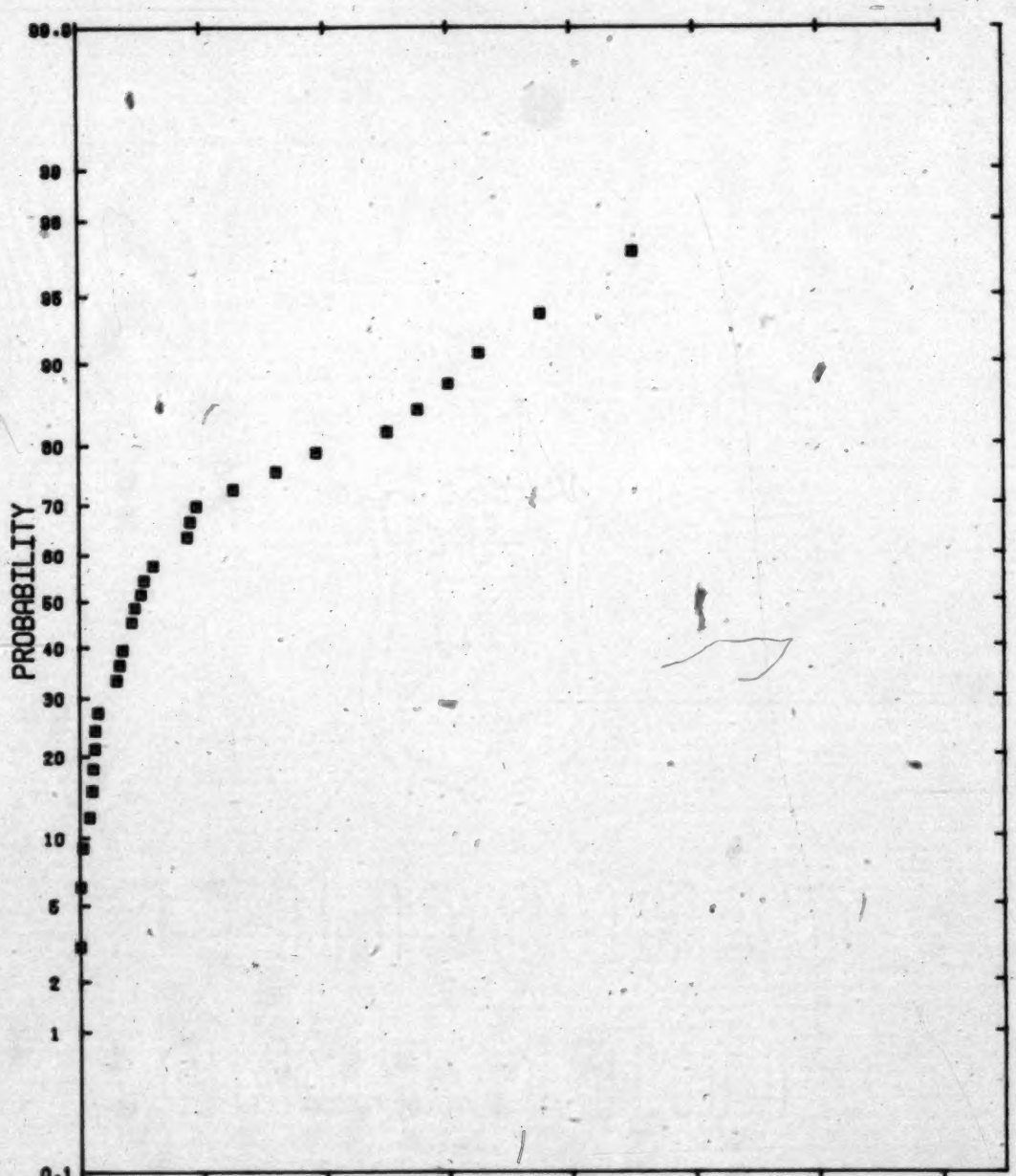
DISINFECTION RESULTS

Day	Total Coliforms/100mL			
	Chlorine 3 mg/L	Chlorine 6 mg/L	Chlorine 9 mg/L	Lime 800 mg/L
1	500	74000	100	100
2	4900	200	200	61000
3	700	400	200	98000
4	500	100	400	43000
5	100	100	100	2500
6	300	100	100	2200
7	100	100	100	18000
8	100	100	100	14000
9	200	300	100	1200
10	100	200	100	5500
11	100	100	100	100
12	100	100	100	21000
13	100	100	2600	800
14	100	100	100	100
15	100	100	100	200
16	500	100	31000	700
17	400	100	100	1600
18	600	100	100	40000
19	100	100	100	100
20	100	100	100	200
21	100	100	100	300
22	100	100	100	100
23	100	100	100	400
24	100	100	100	100
25	700	4500	100	200
26	100	100	100	100



PROBABILITY PLOT WHALE COVE

Fig. AI



PROBABILITY PLOT WHALE COVE

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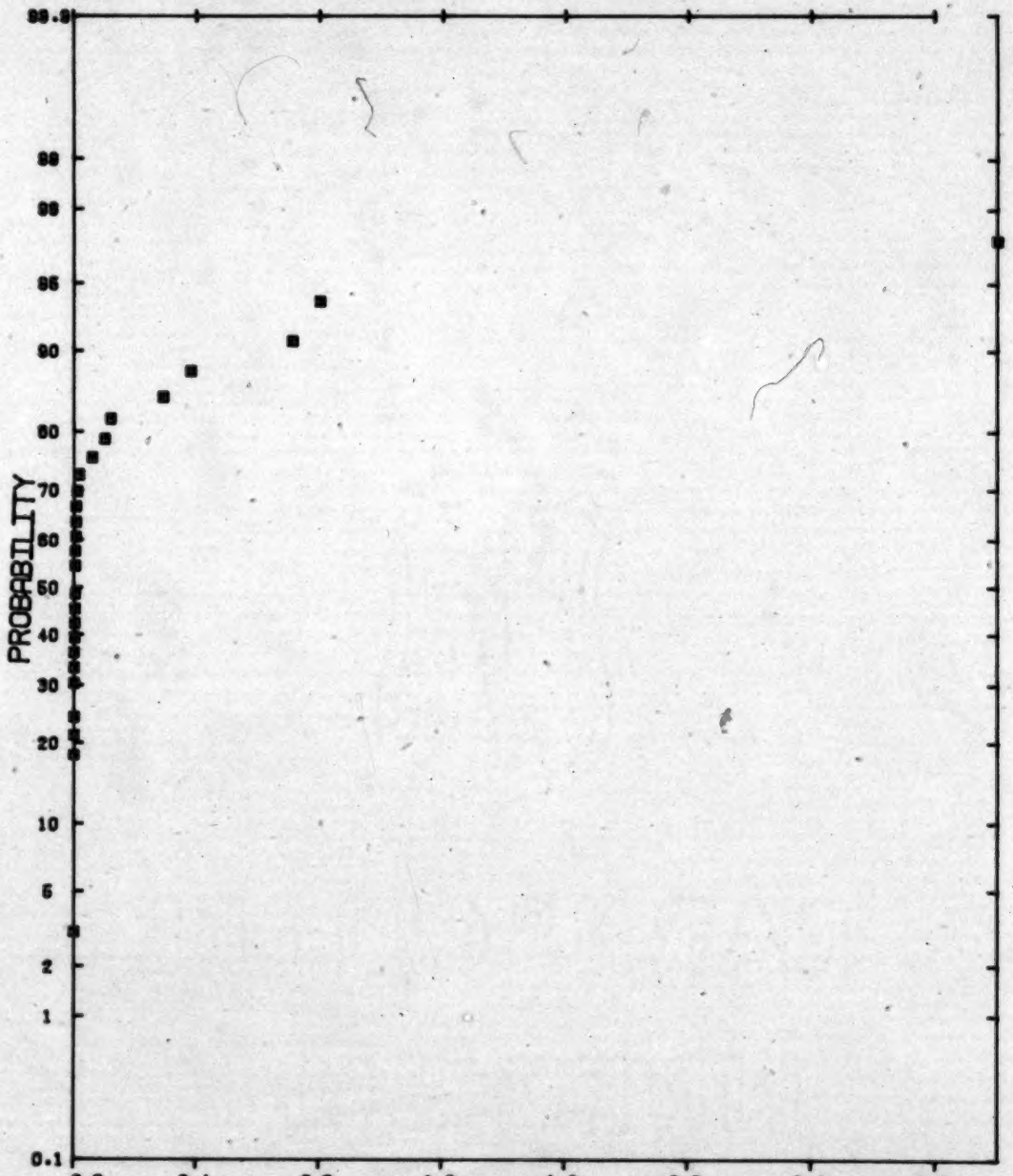
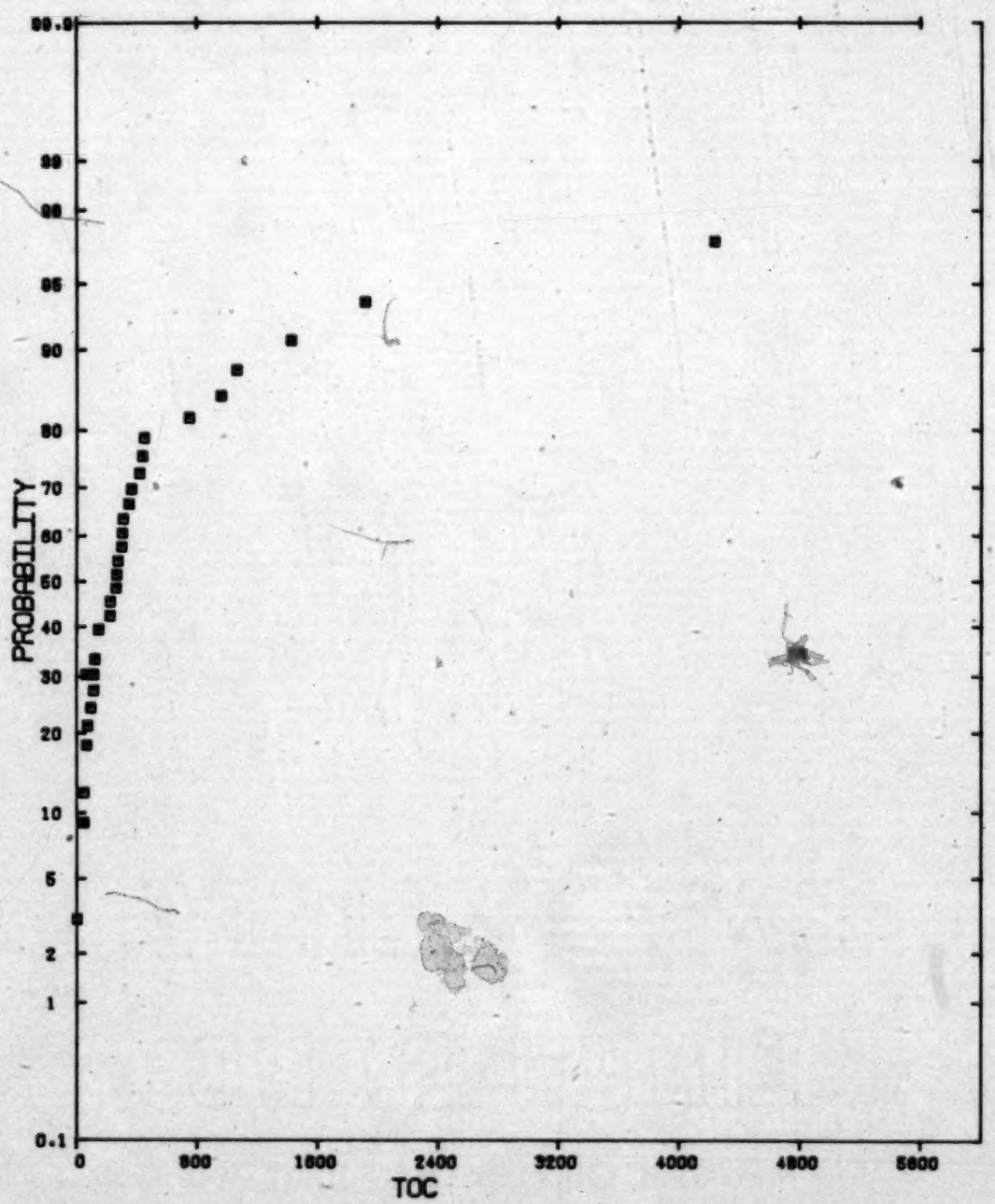


PROBABILITY PLOT WHALE COVE

Fig. A3



PROBABILITY PLOT WHALE COVE

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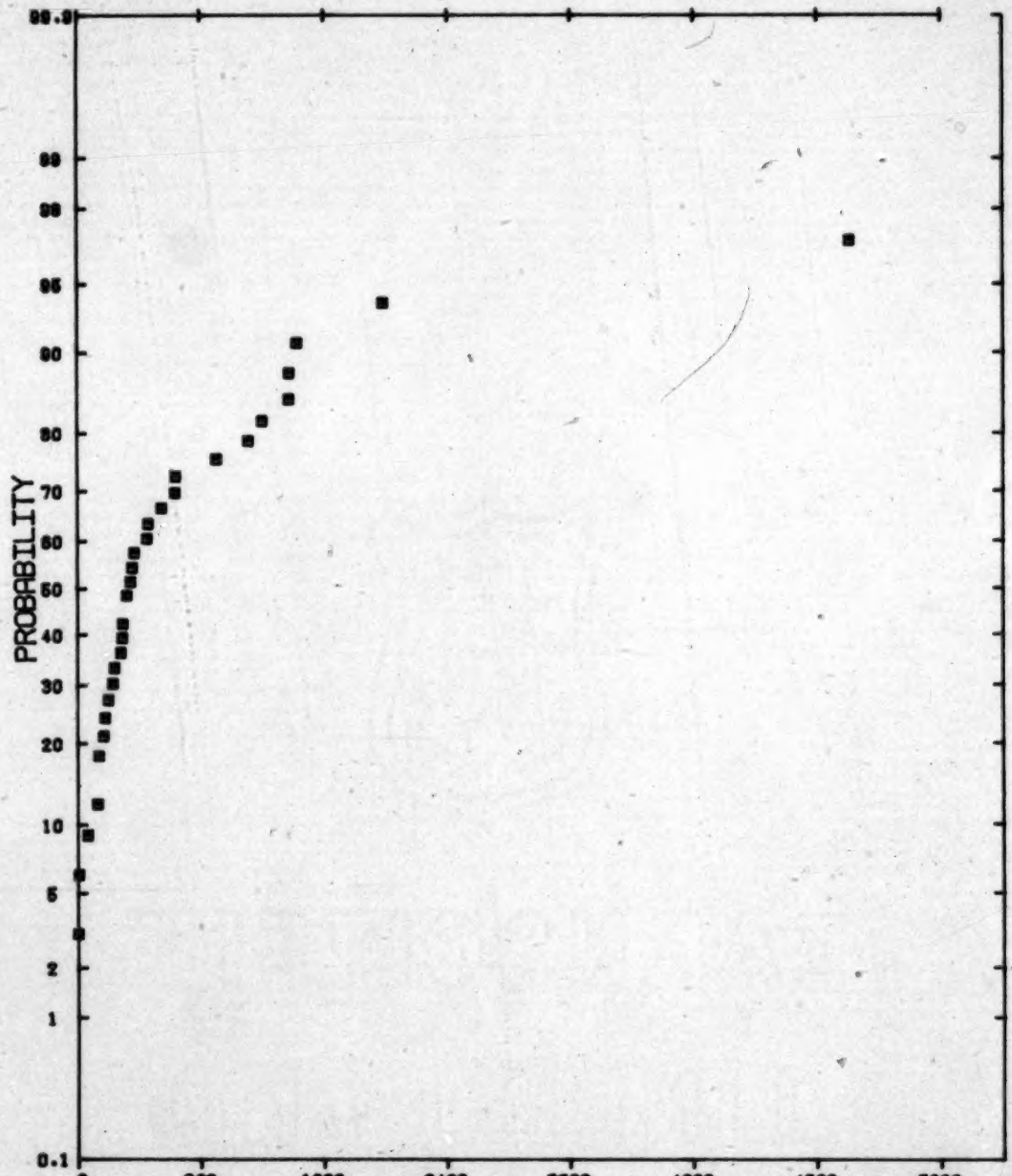

PROBABILITY PLOT WHALE COVE

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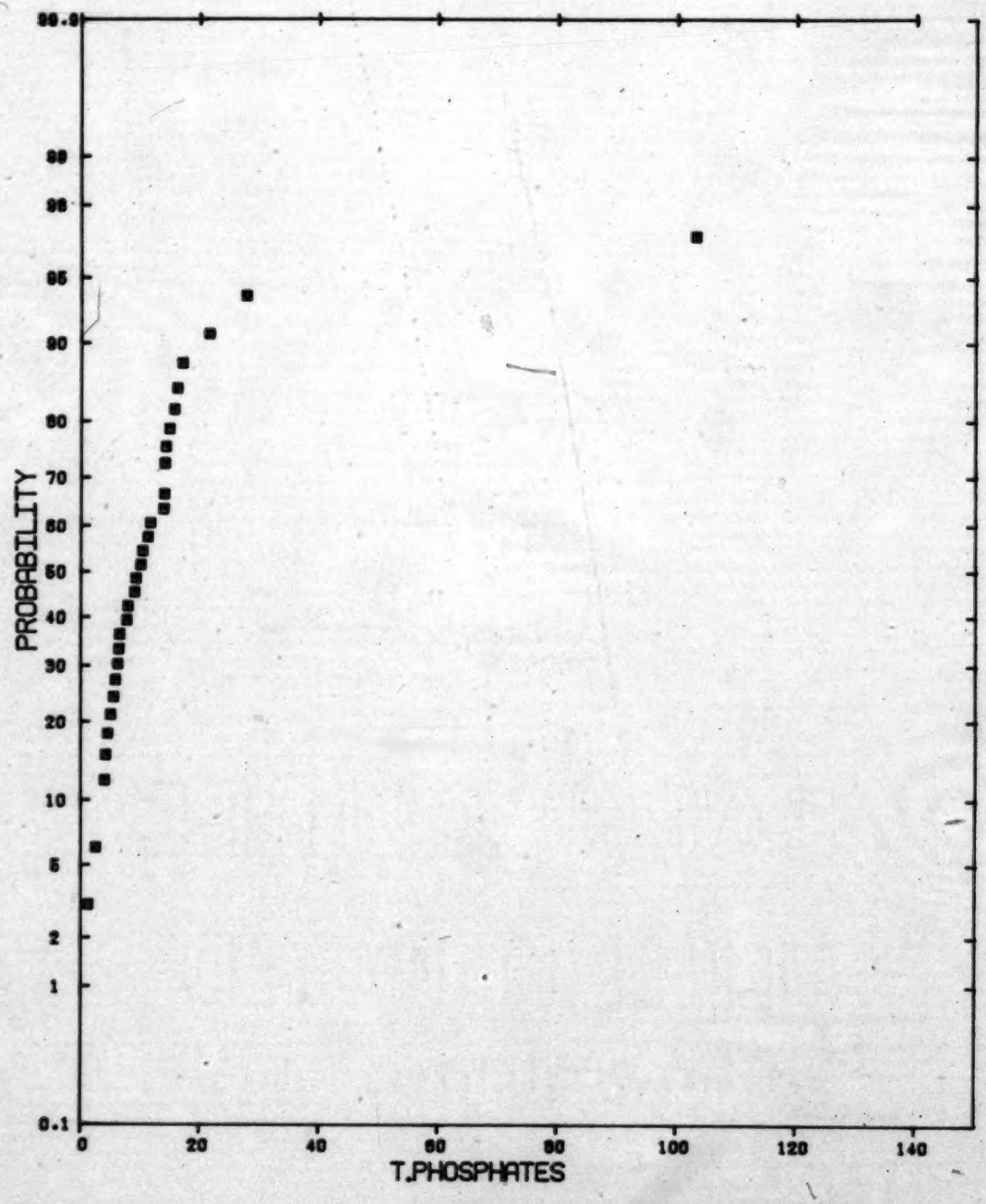

PROBABILITY PLOT WHALE COVE

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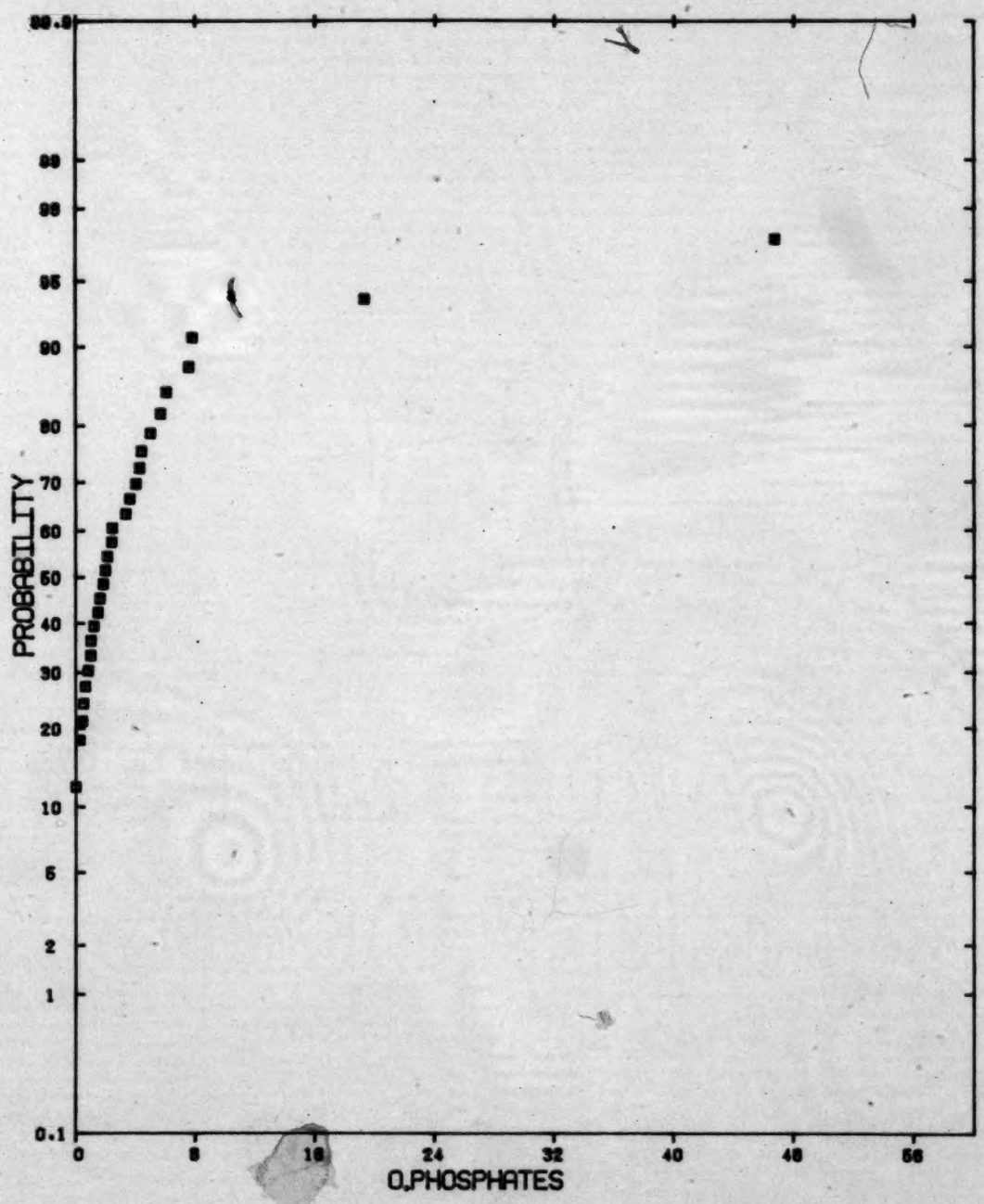
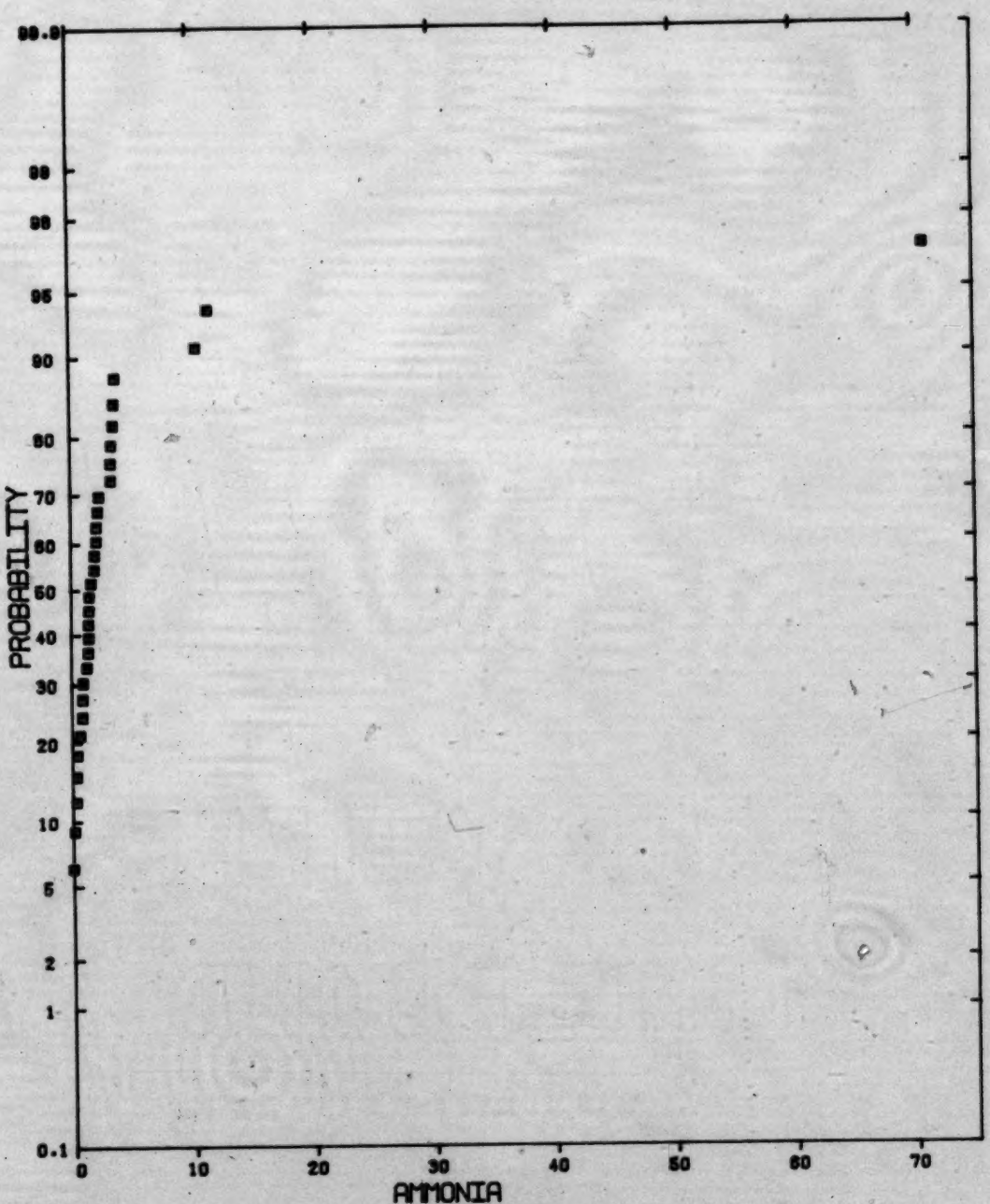


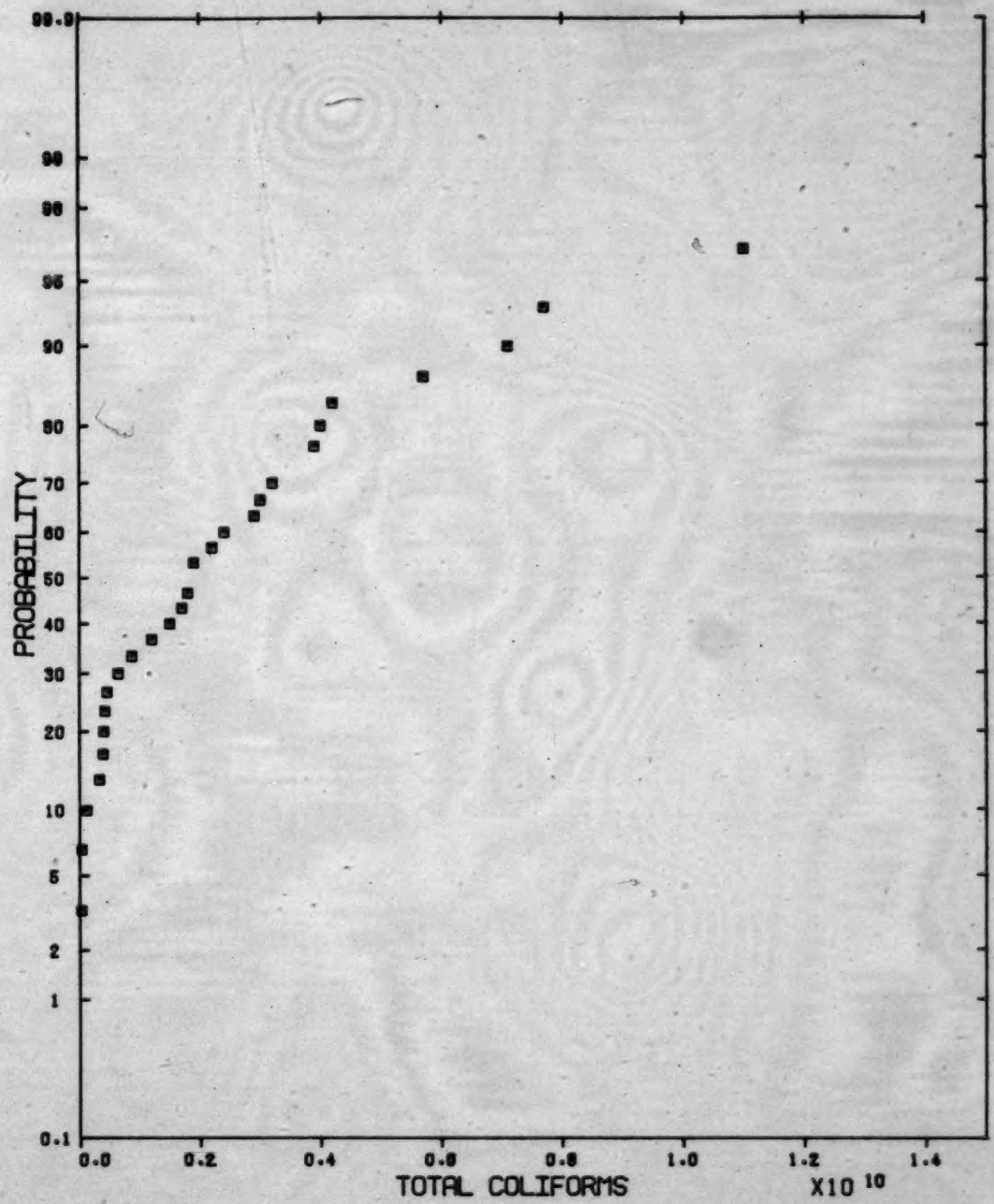
PROBABILITY PLOT WHALE COVE

Fig. A7



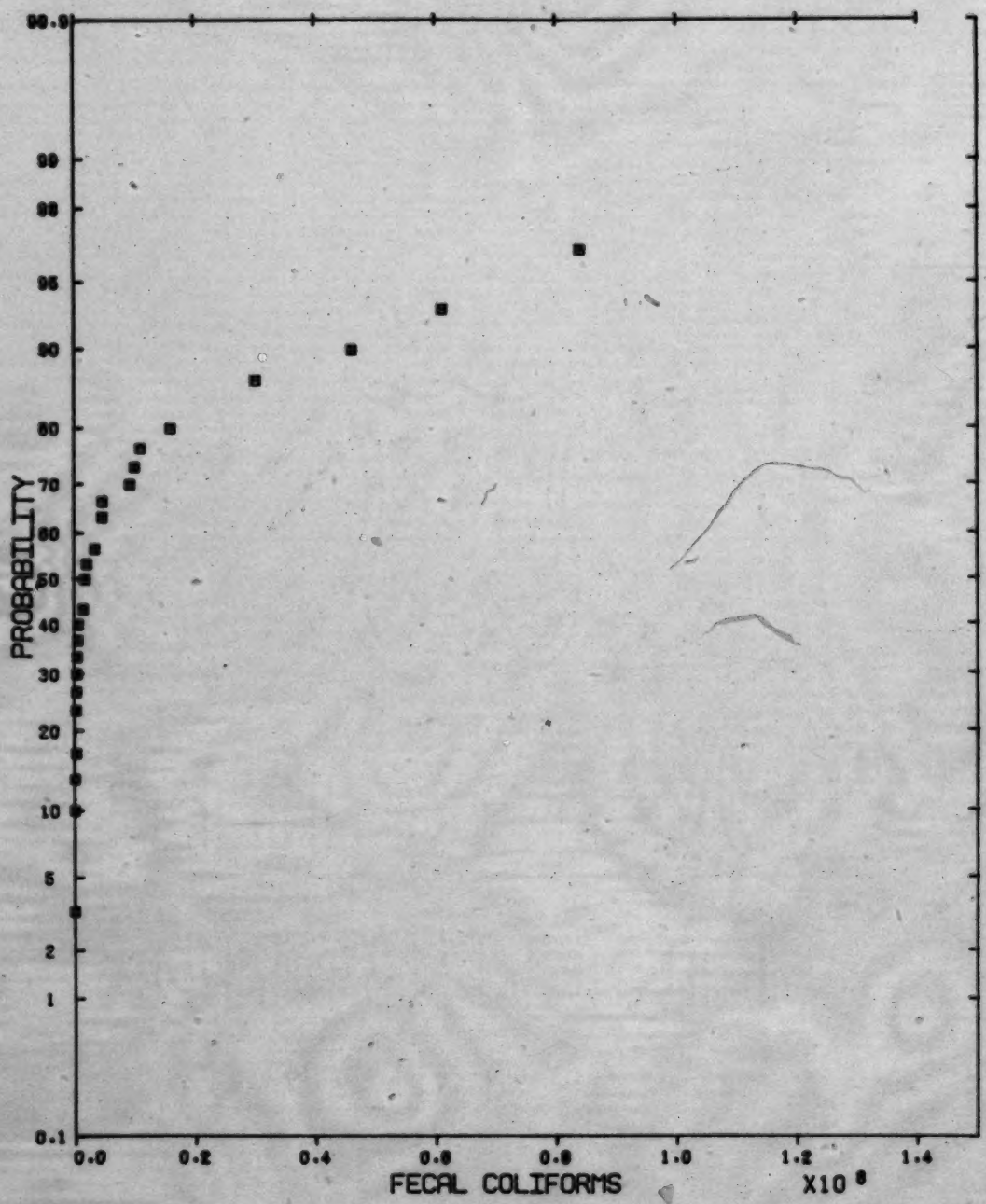
PROBABILITY PLOT WHALE COVE

Fig. A8



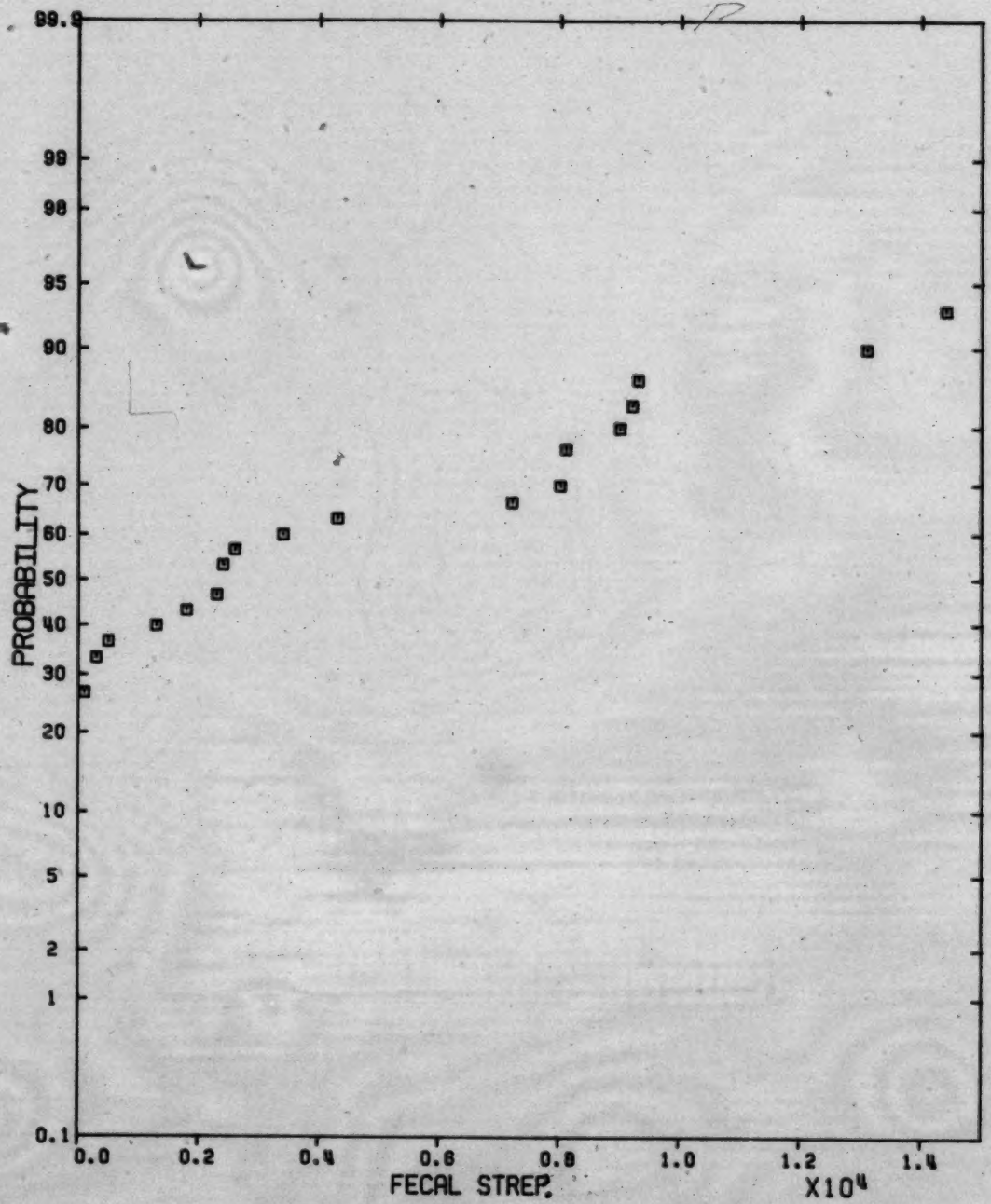
PROBABILITY PLOT EDMONTON

Fig. A9



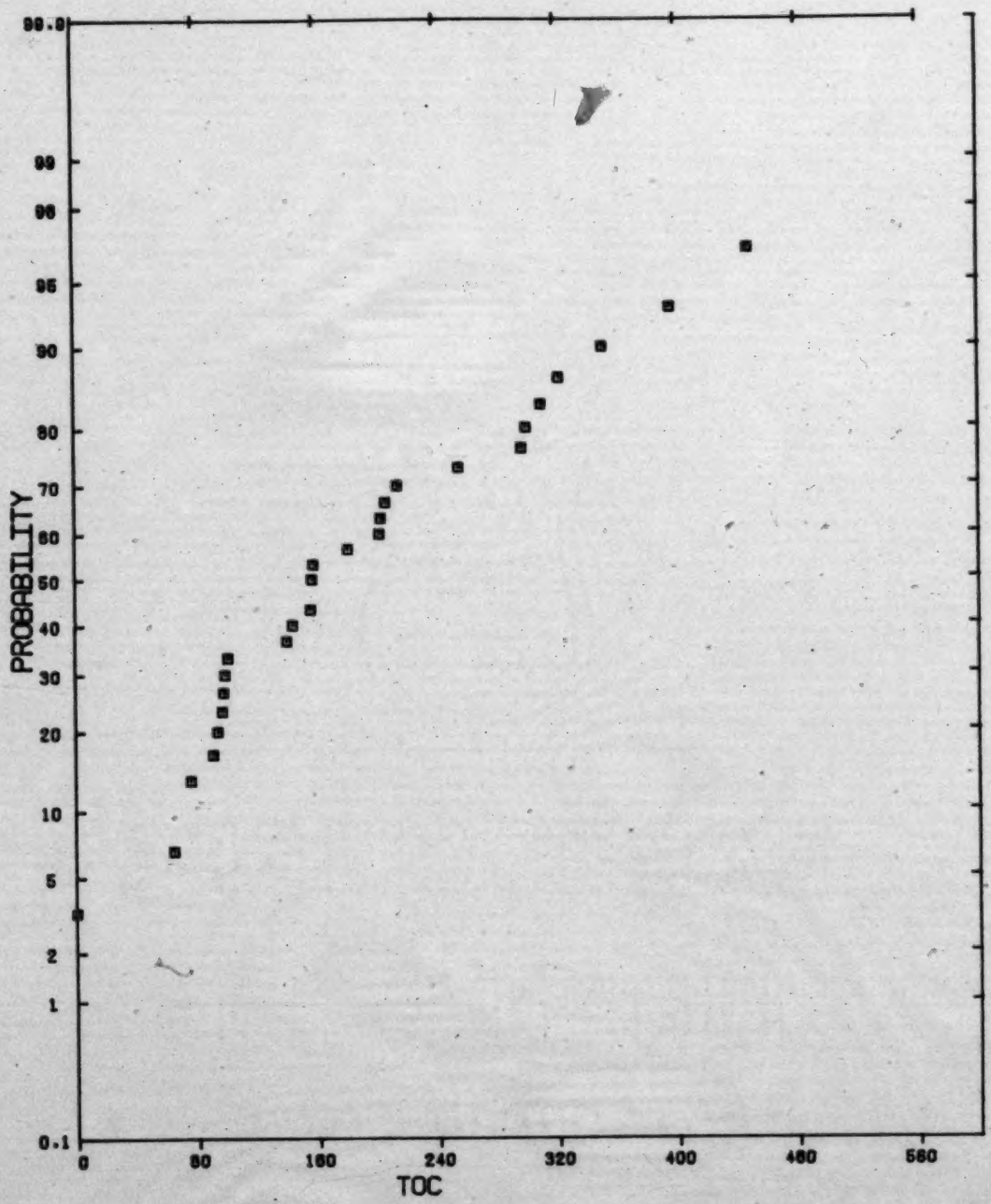
PROBABILITY PLOT EDMONTON

Fig. AIO



PROBABILITY PLOT EDMONTON

Fig. AII



PROBABILITY PLOT EDMONTON

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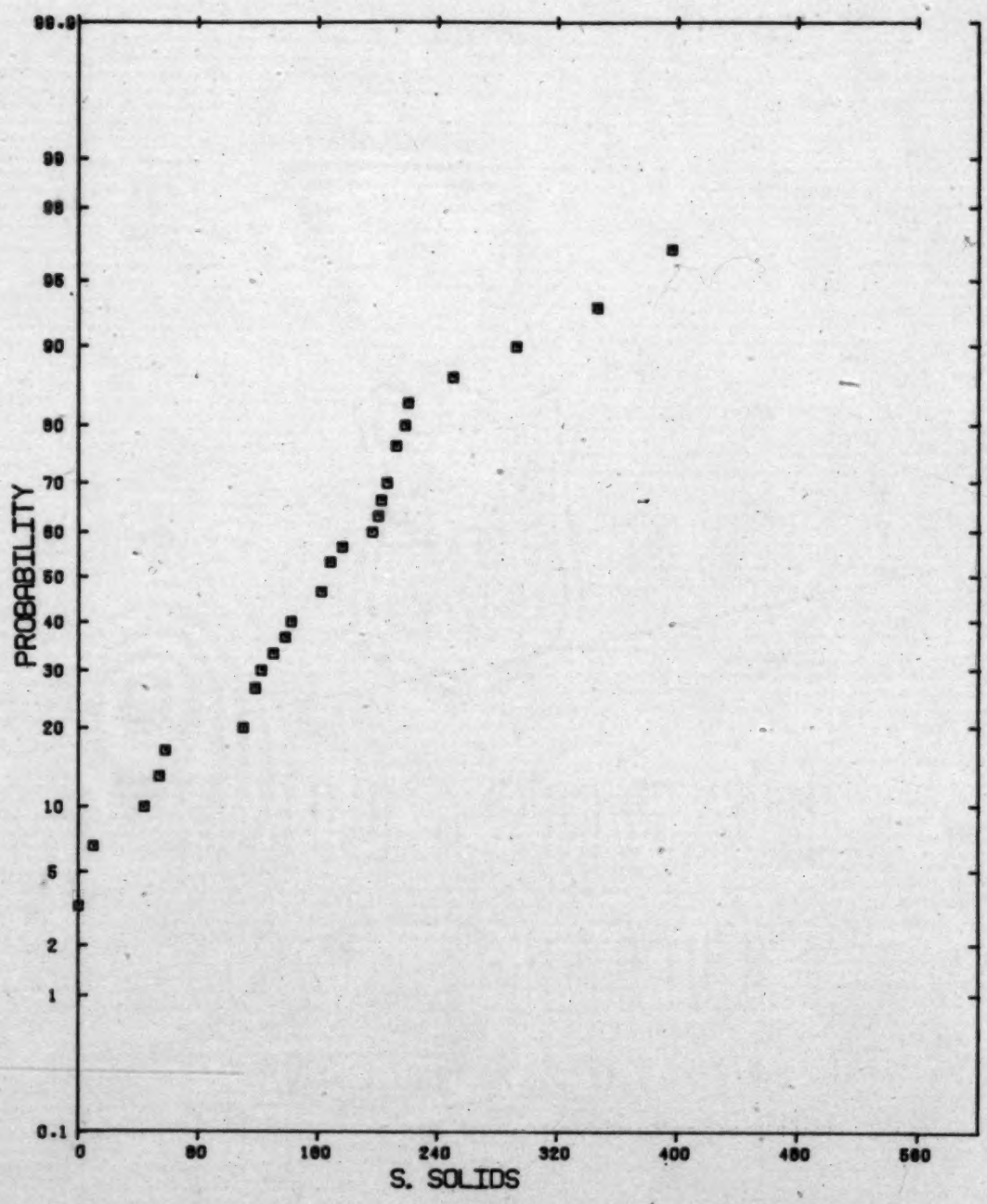

PROBABILITY PLOT EDMONTON

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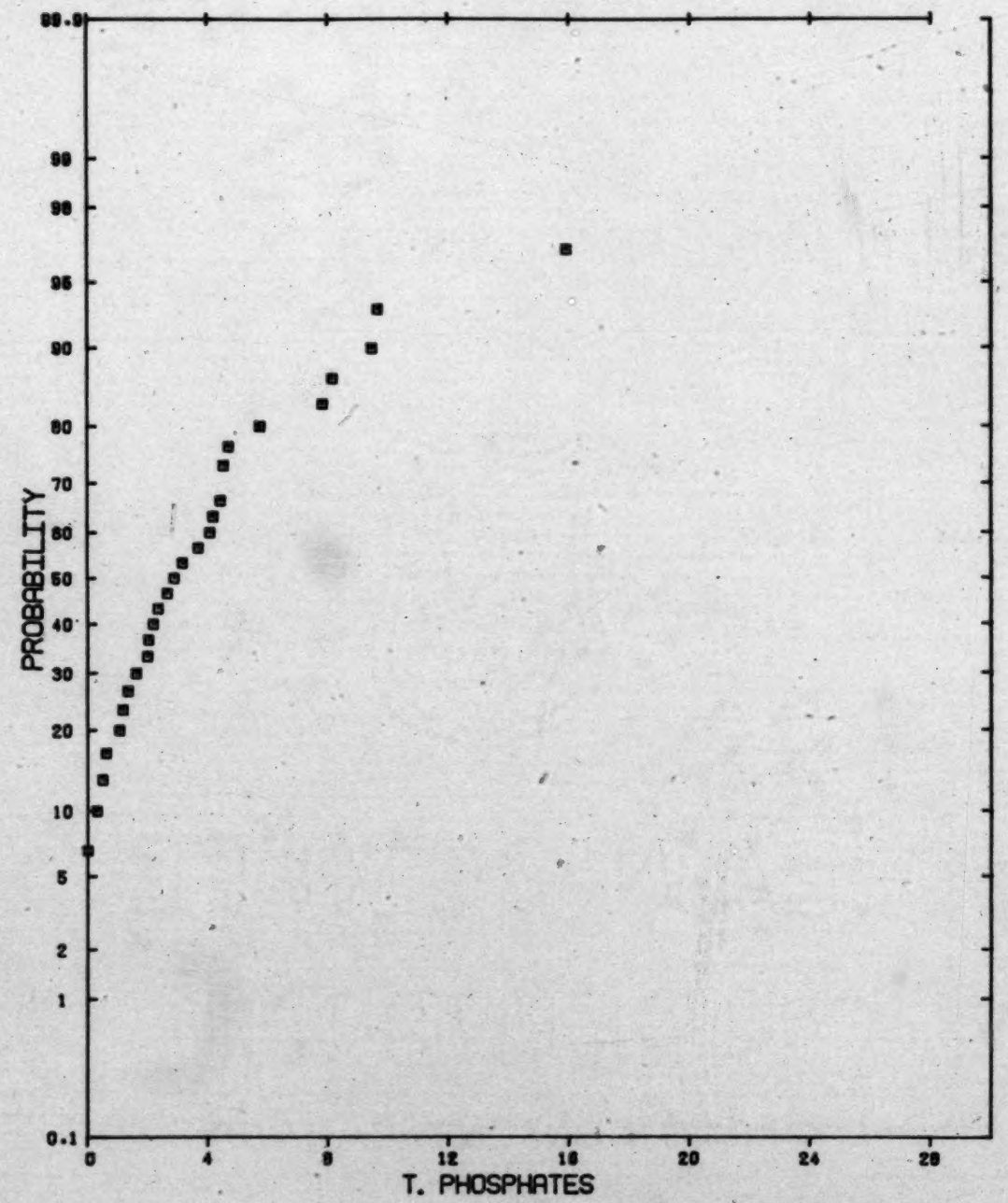

PROBABILITY PLOT EDMONTON

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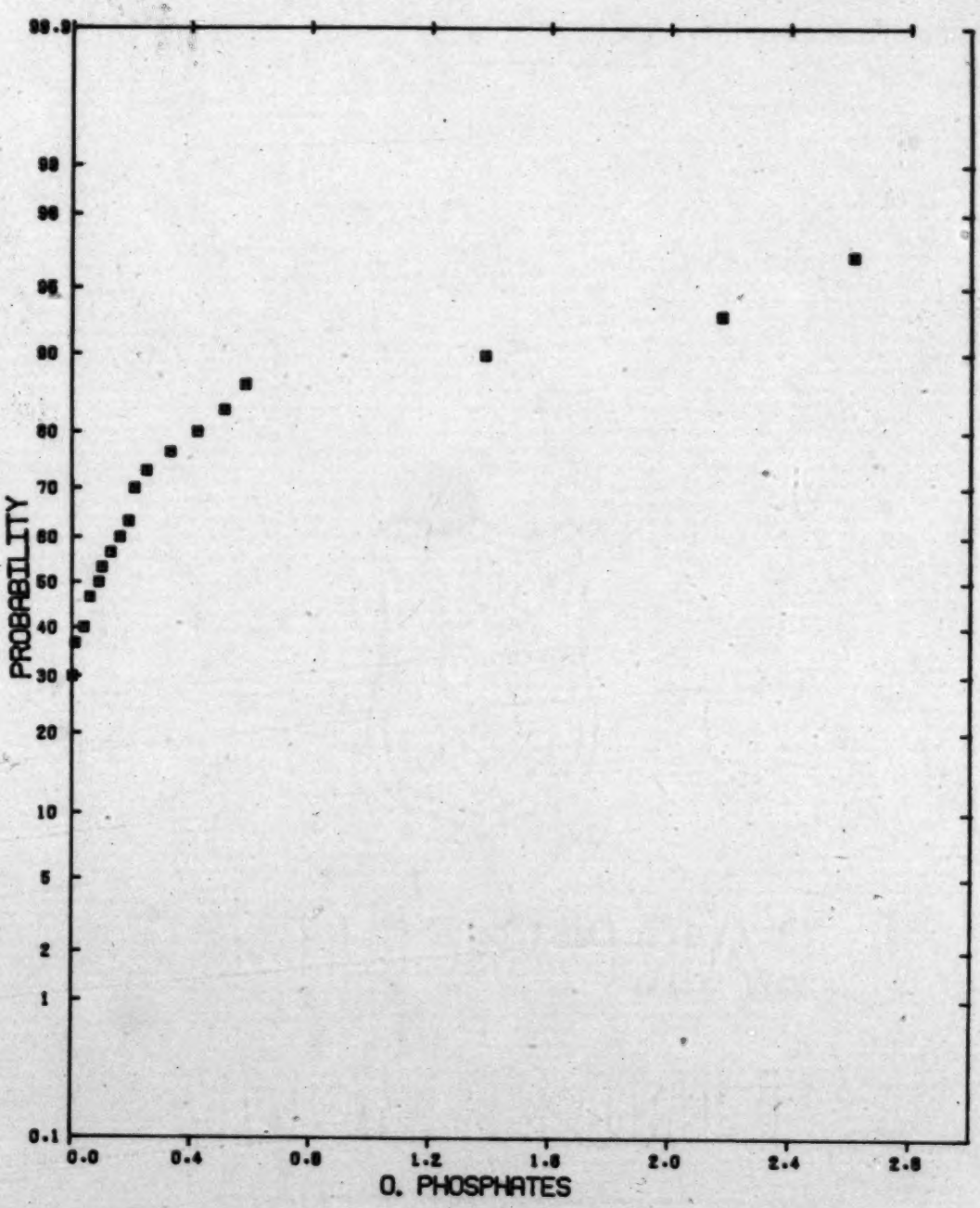

PROBABILITY PLOT EDMONTON

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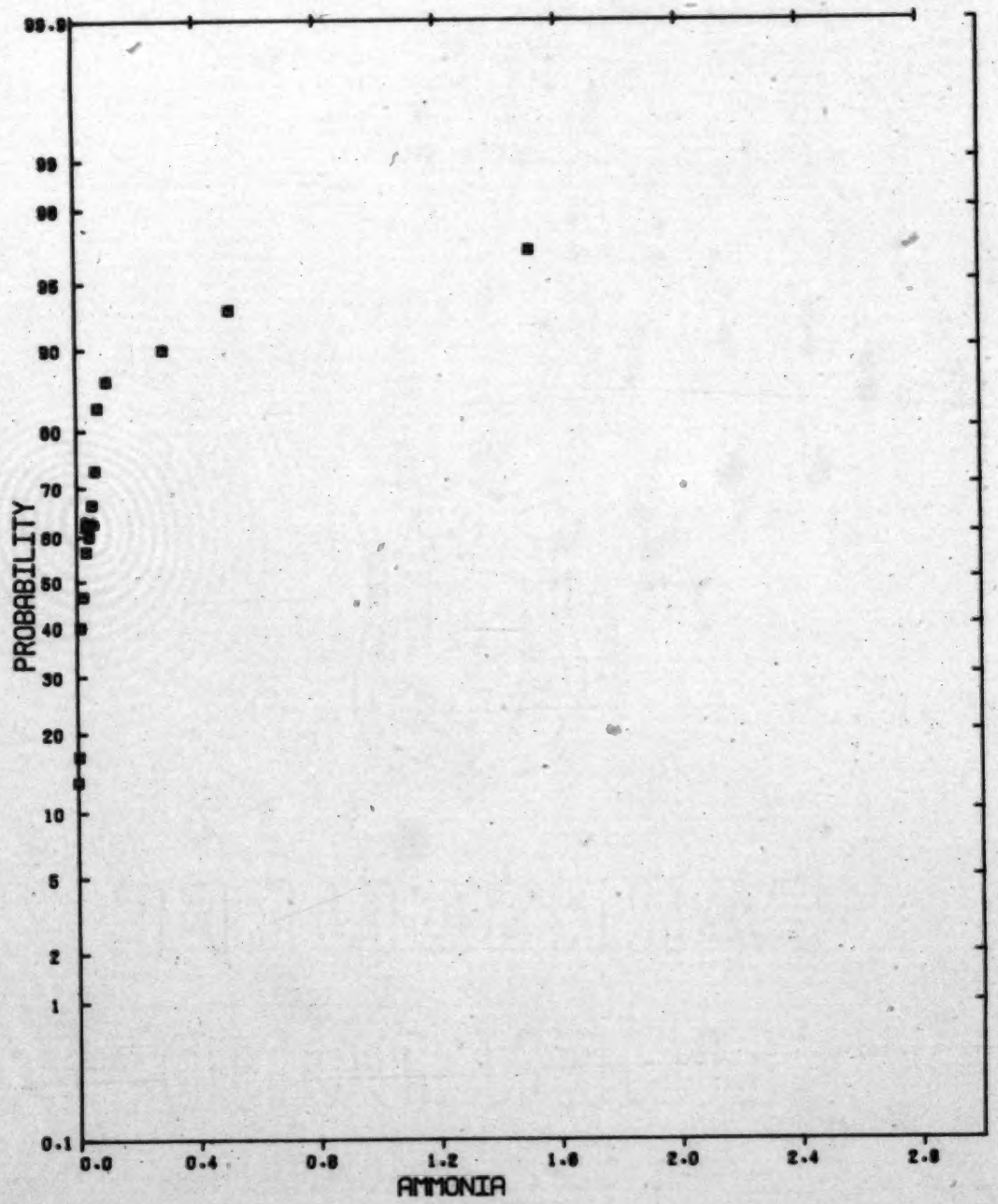

PROBABILITY PLOT EDMONTON

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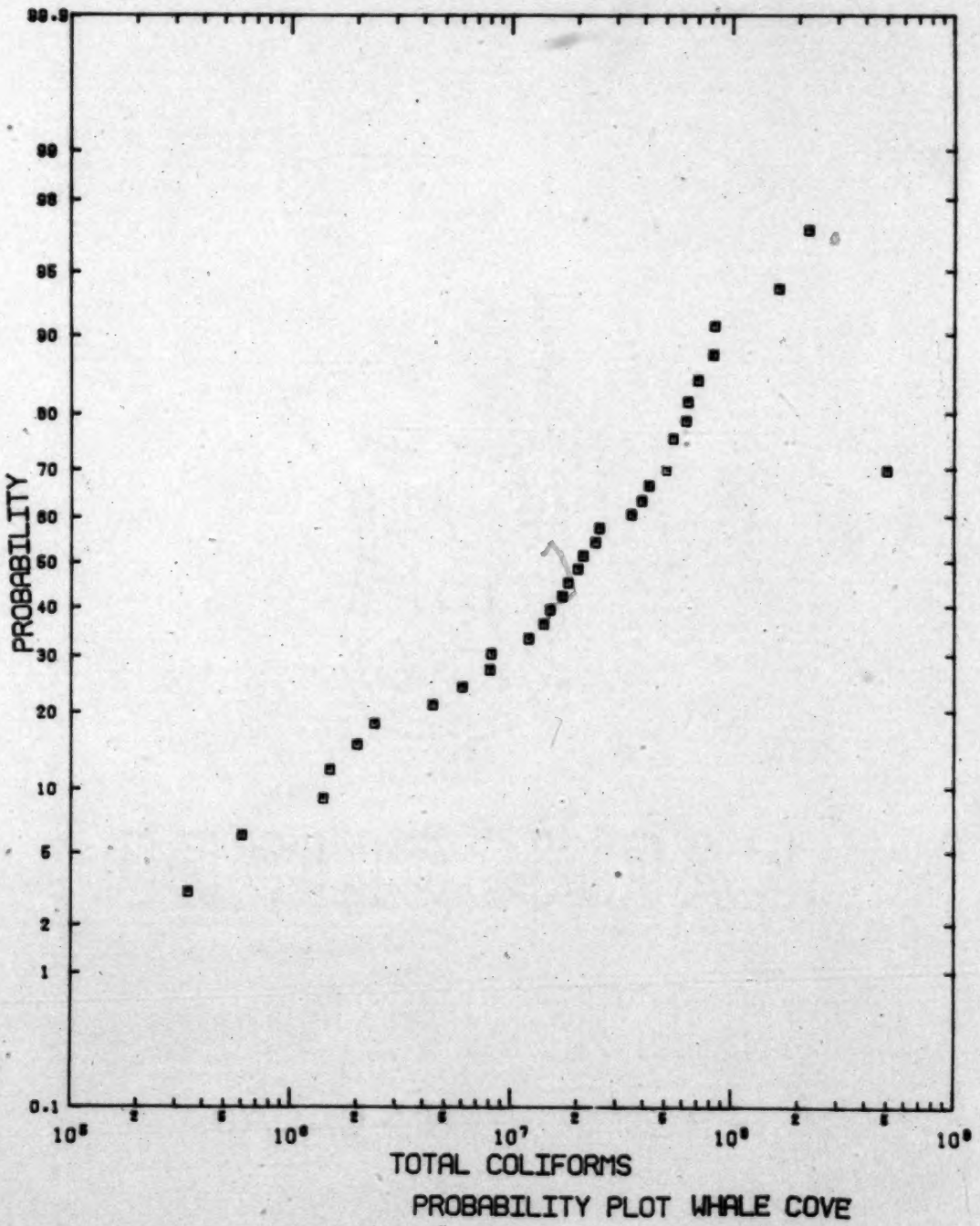
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40
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20
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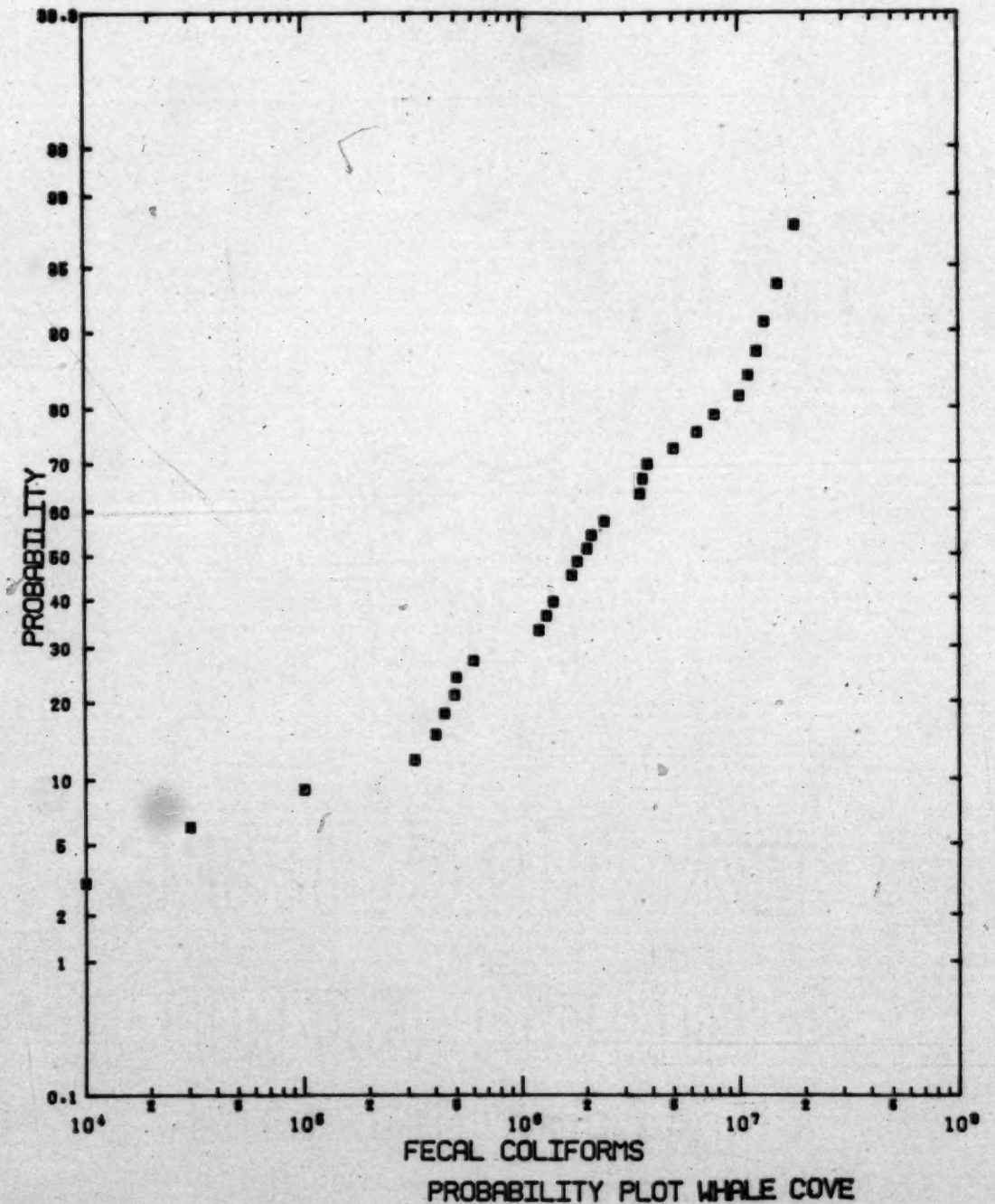
10^6
10^7
10^8
10^9
TOTAL COLIFORMS
PROBABILITY PLOT WHALE COVE

Fig. AI7



PROBABILITY PLOT WHALE COVE

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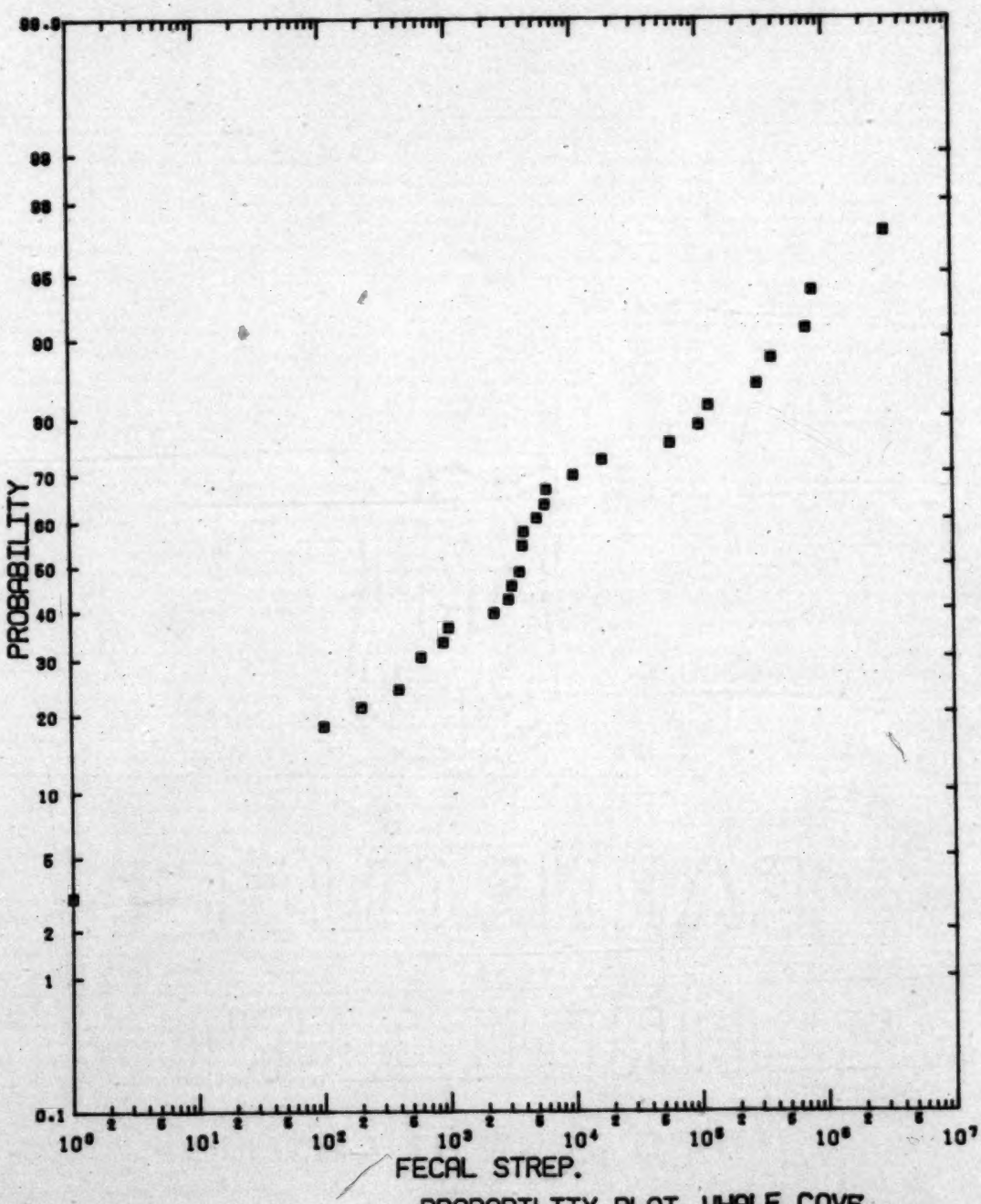

PROBABILITY PLOT WHALE COVE

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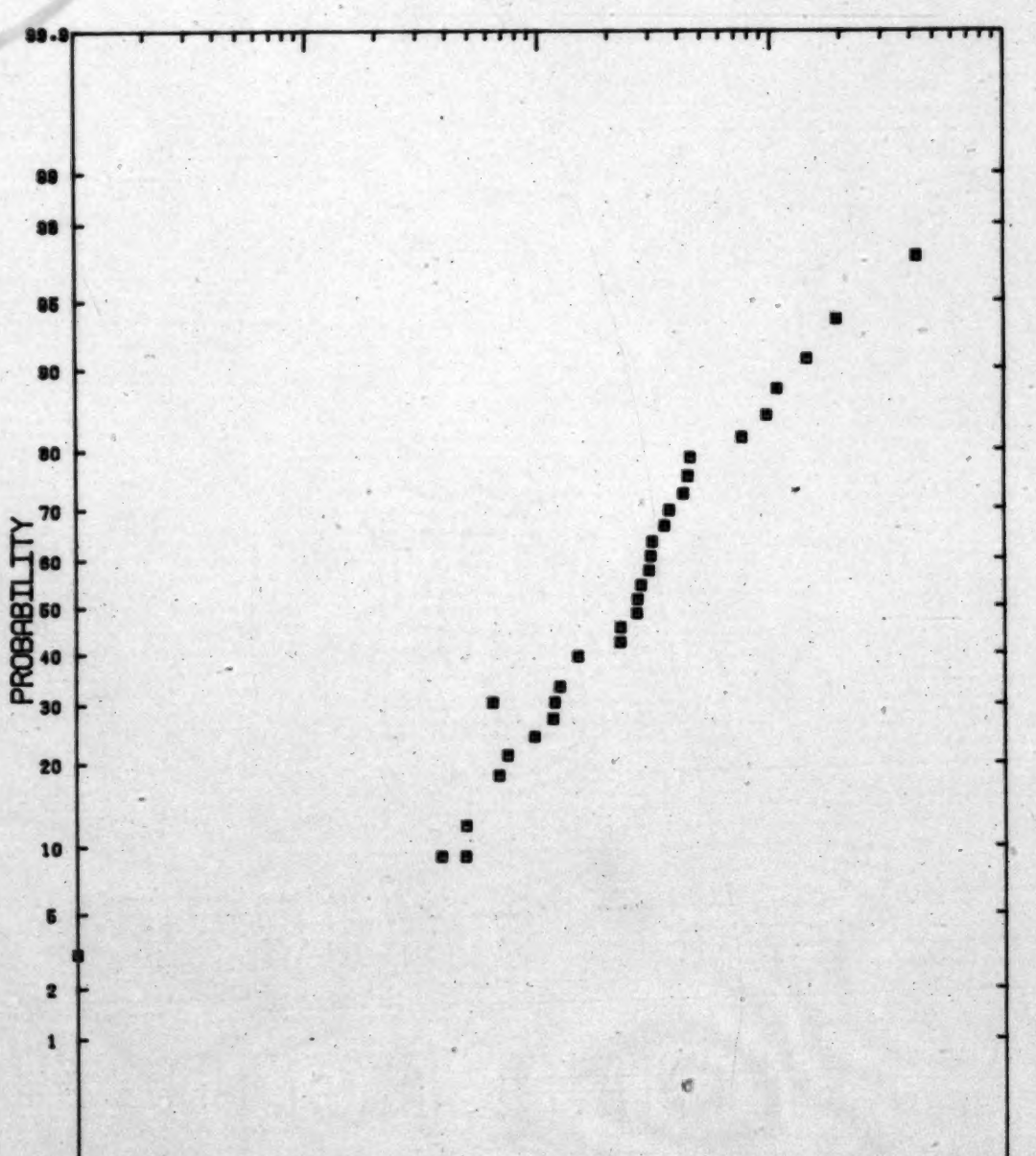
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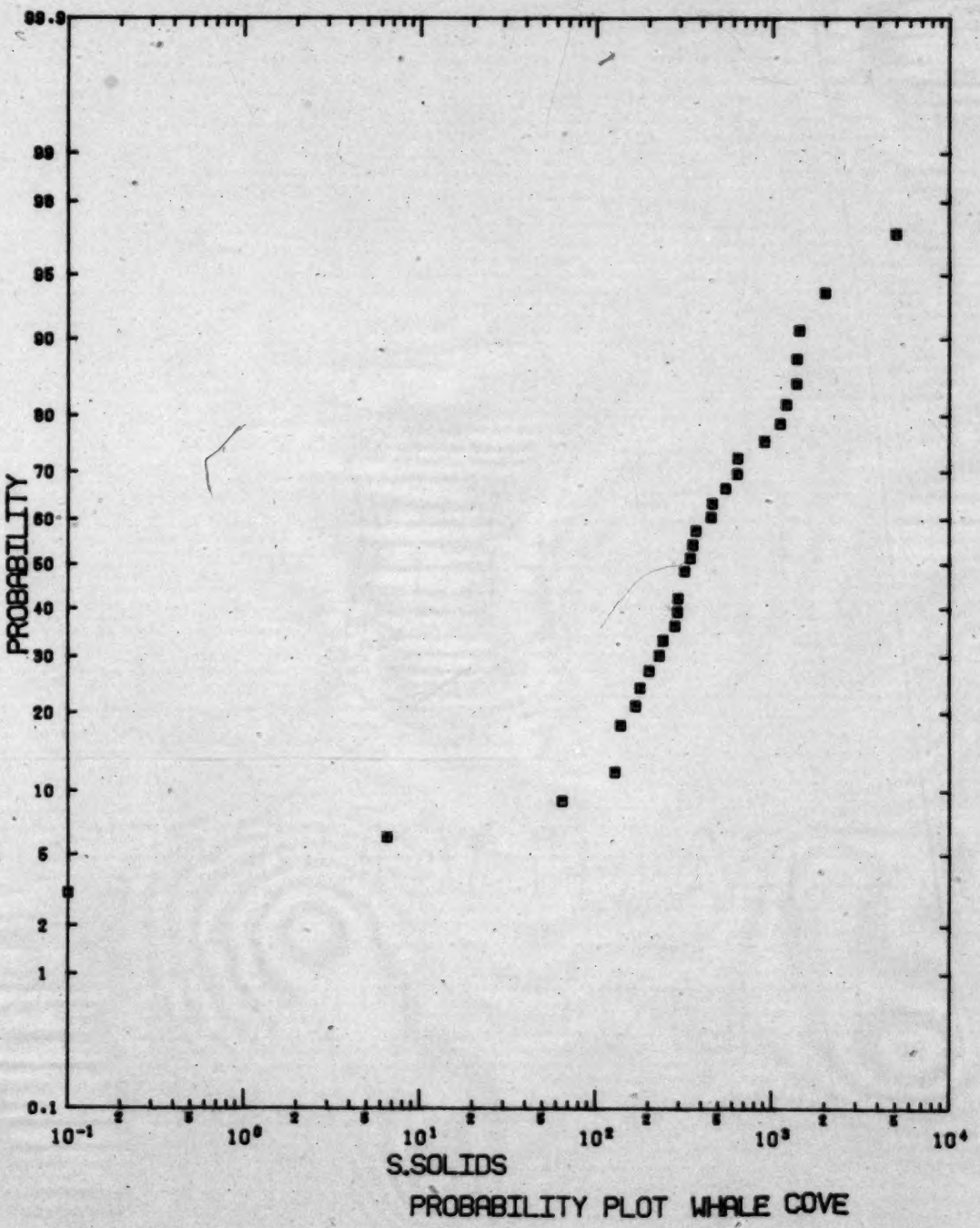
TOC
PROBABILITY PLOT WHALE COVE

Fig. A20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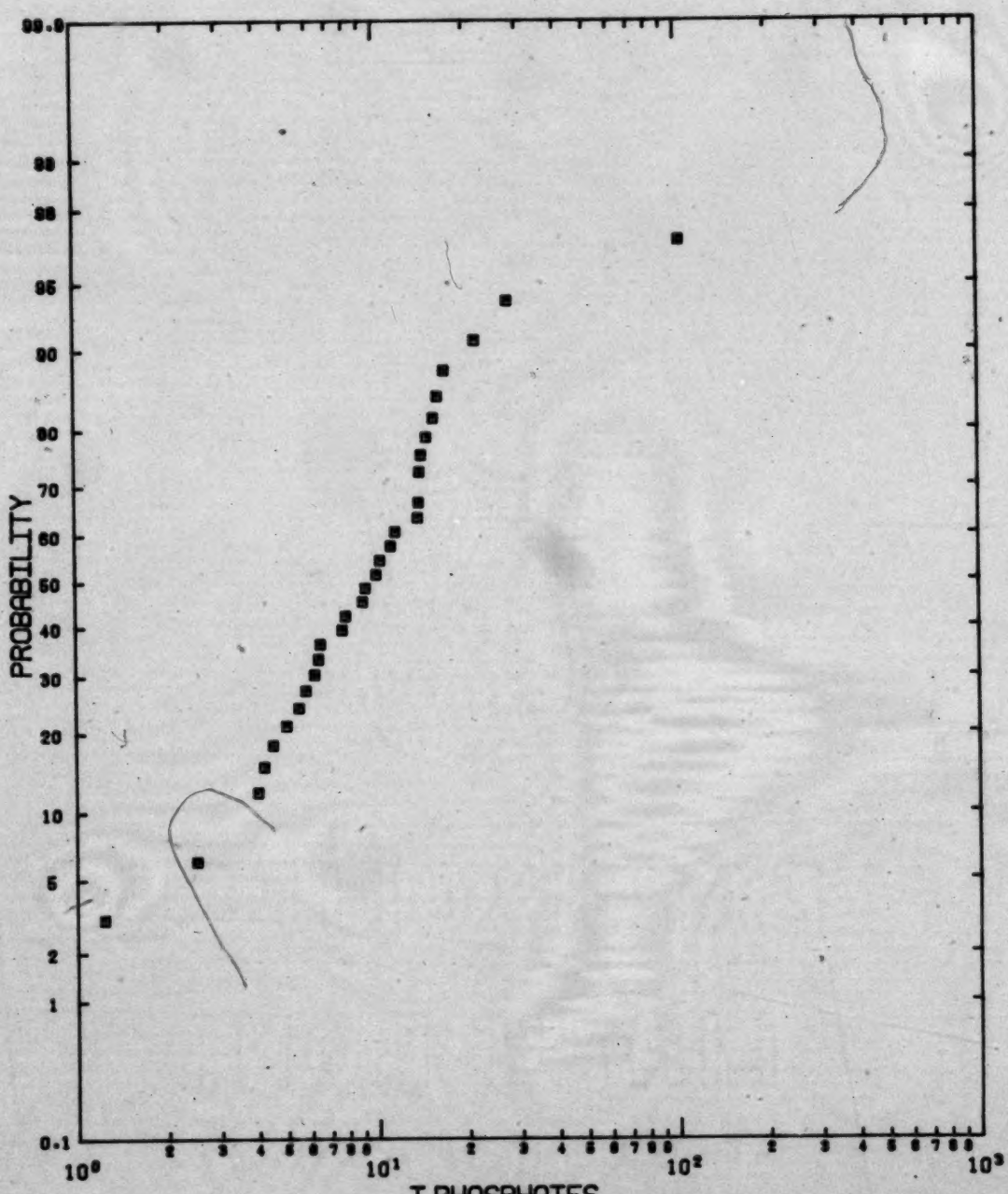
10^{4}
S.SOLIDS
PROBABILITY PLOT WHALE COVE

Fig. A2I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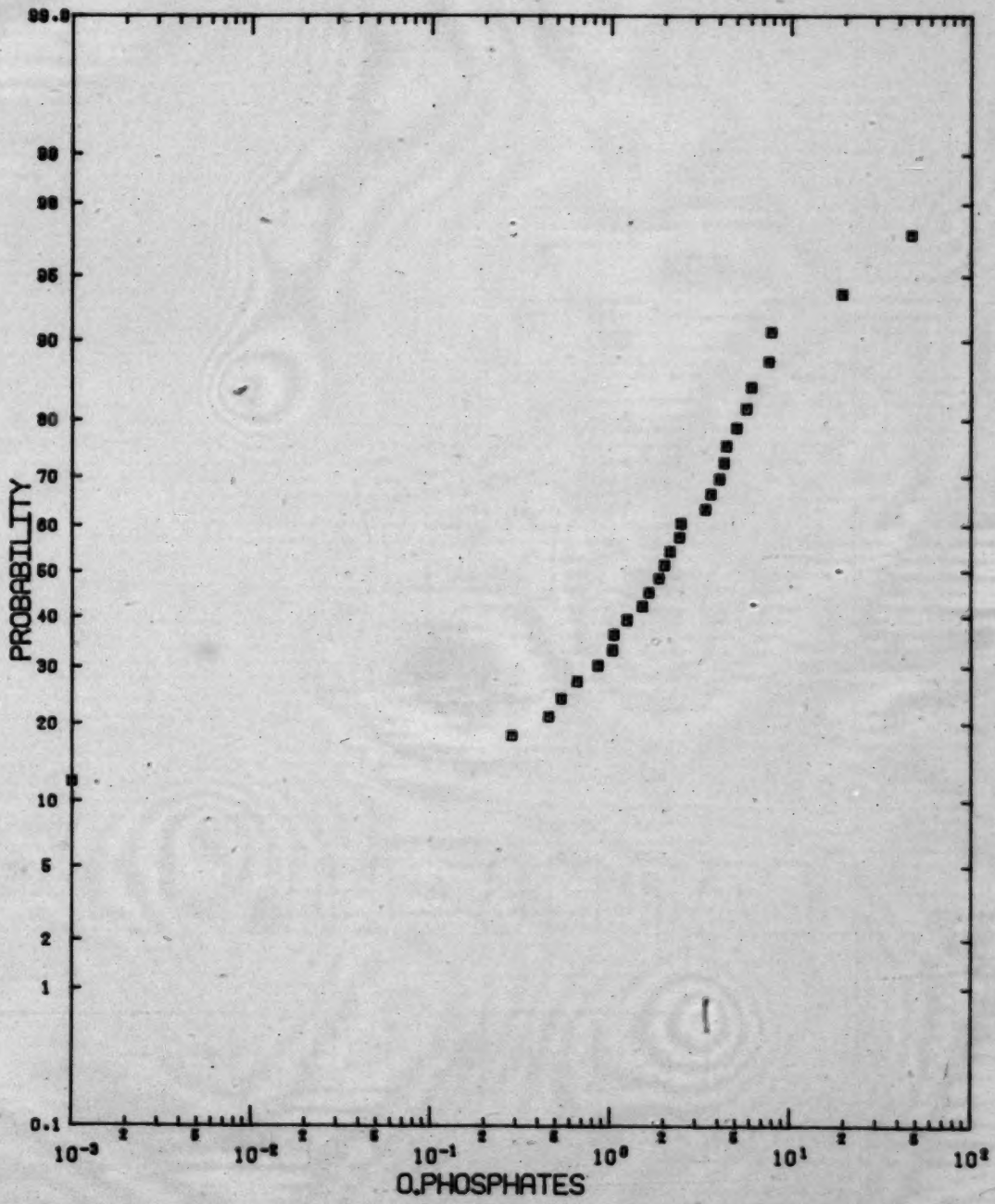
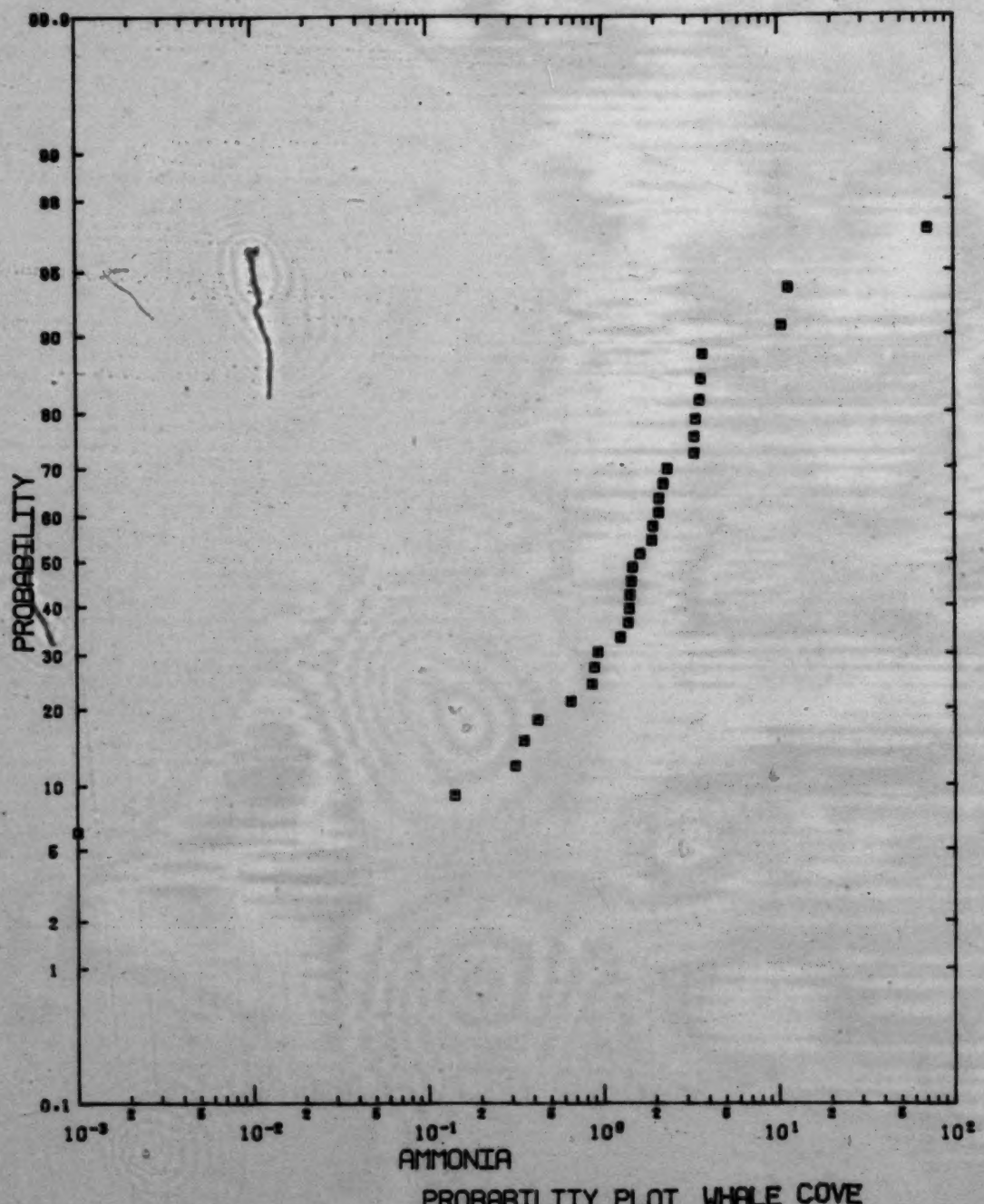
10^3
T.PHOSPHATES
PROBABILITY PLOT WHALE COVE

Fig. A22



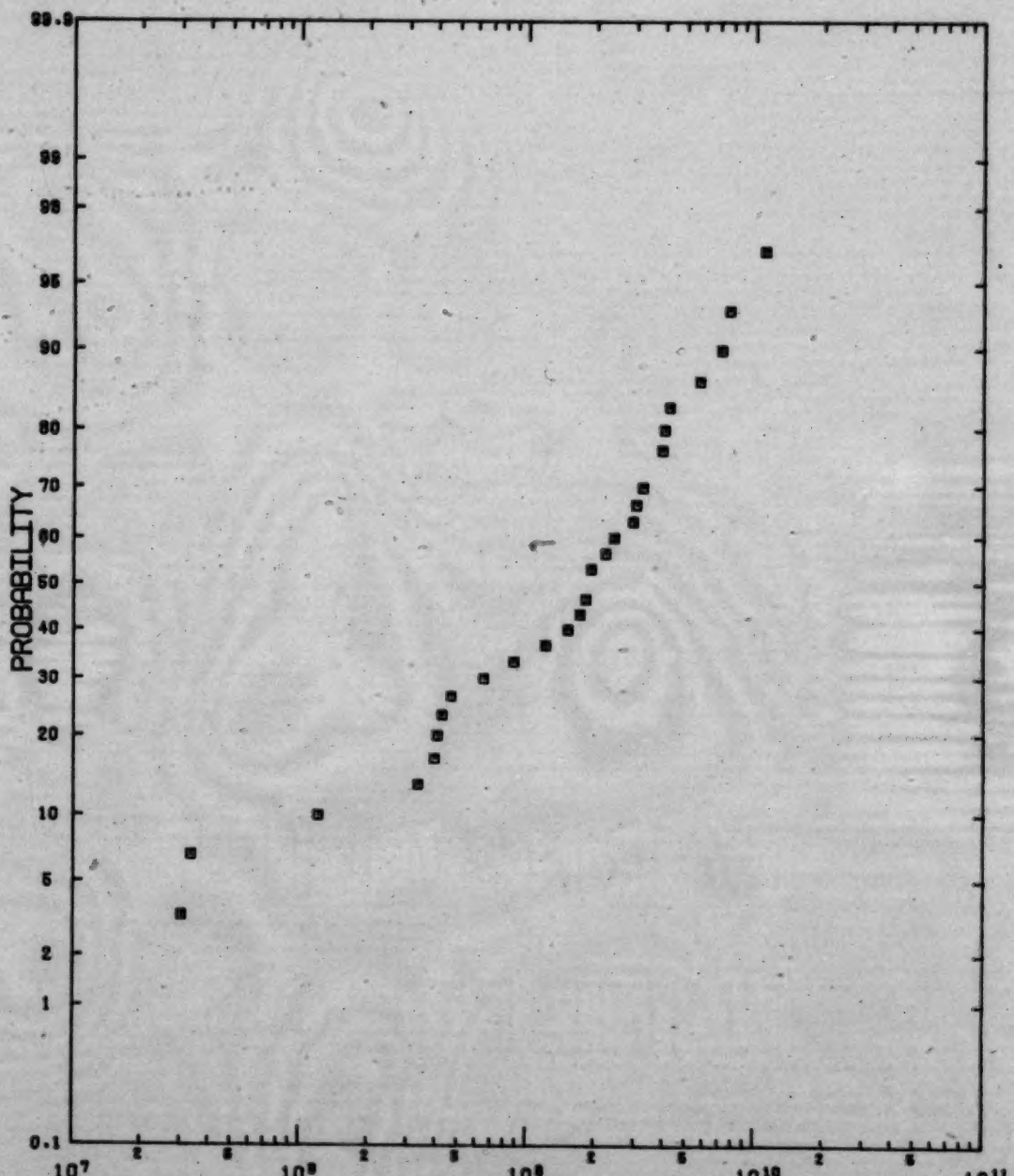
PROBABILITY PLOT WHALE COVE

Fig. A23



PROBABILITY PLOT WHALE COVE

Fig. A24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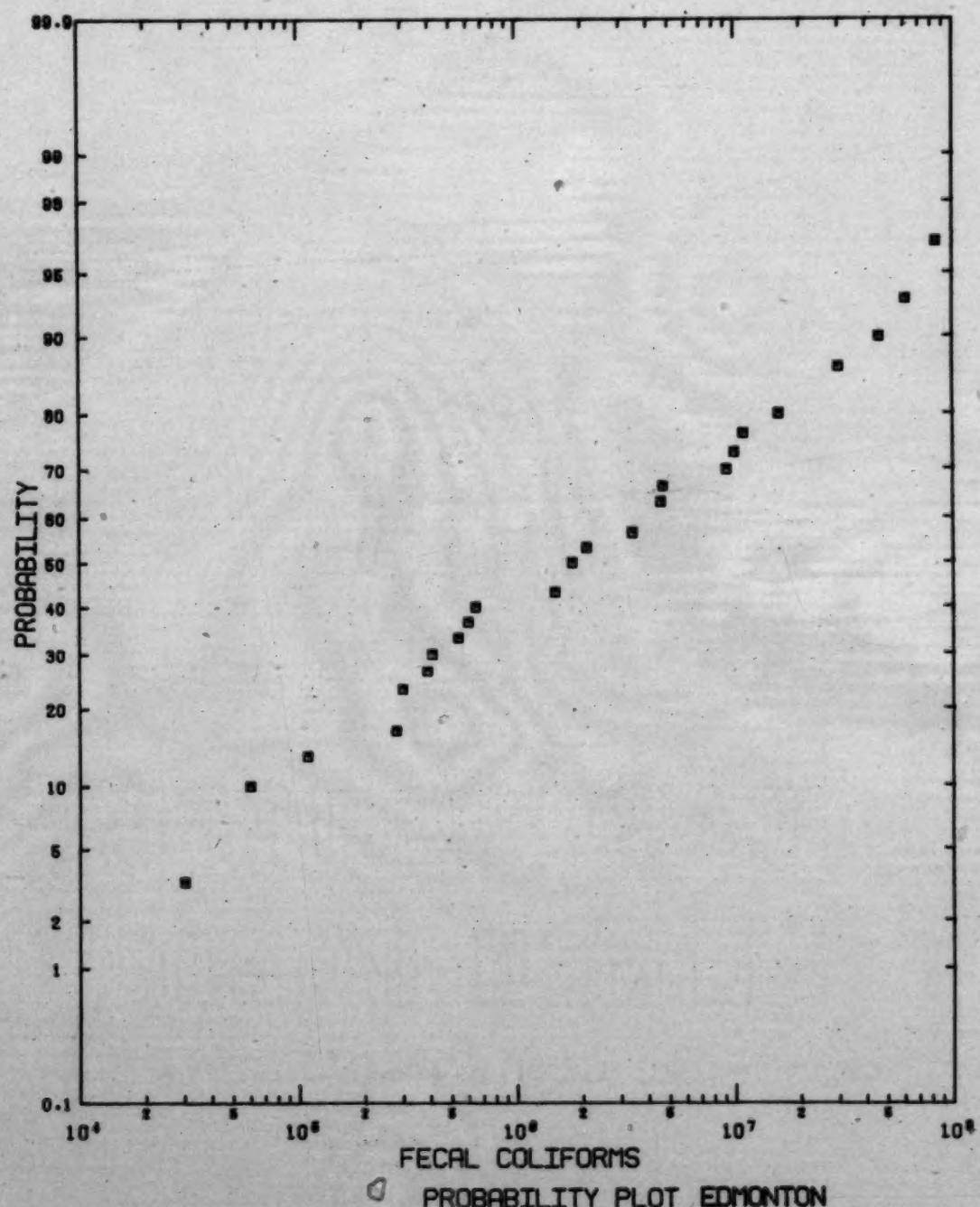
10^9
10^{10}
10^{11}
TOTAL COLIFORMS
PROBABILITY PLOT EDMONTON

Fig. A25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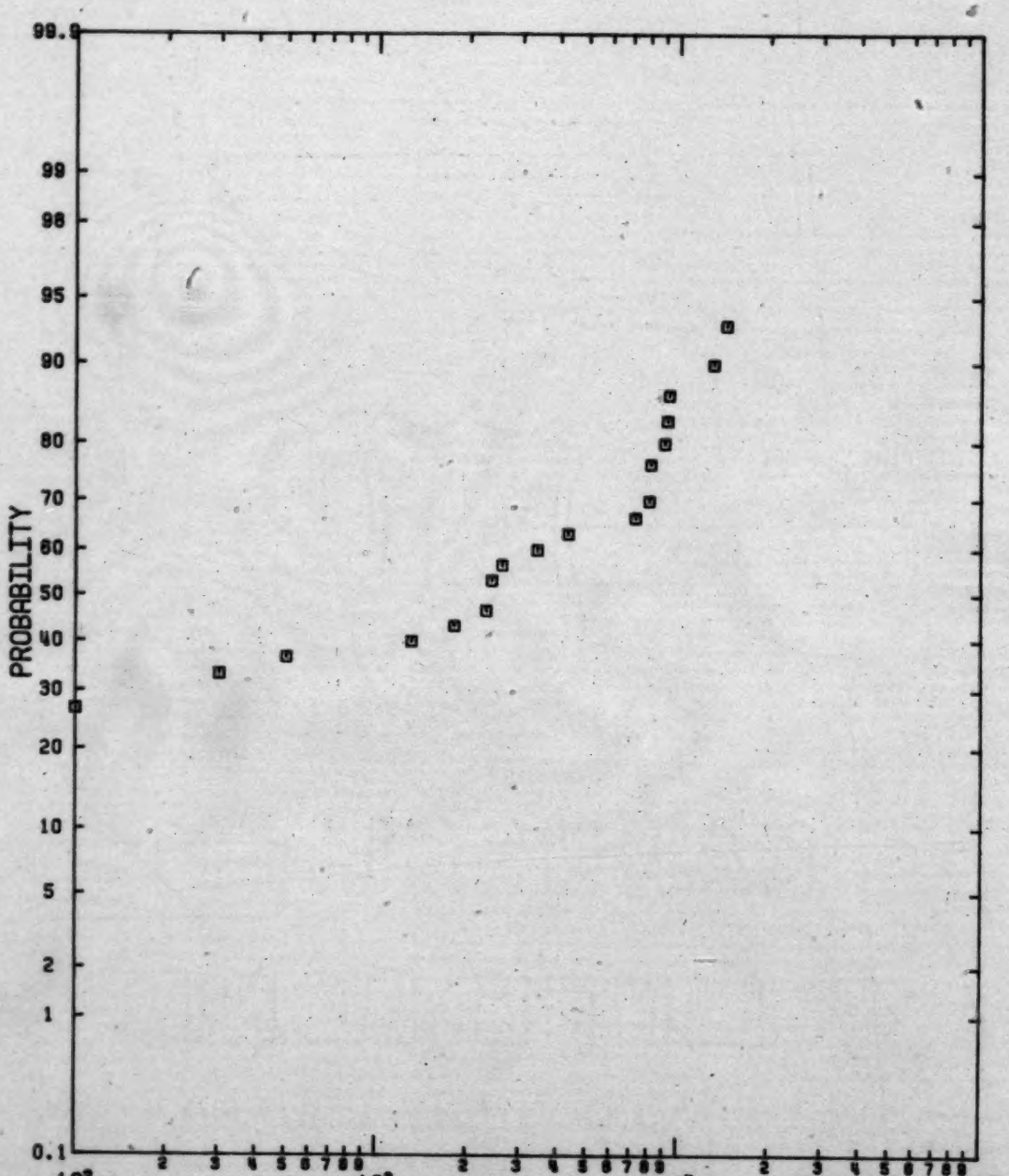
10^7
10^8
FECAL COLIFORMS
PROBABILITY PLOT EDMONTON

Fig. A26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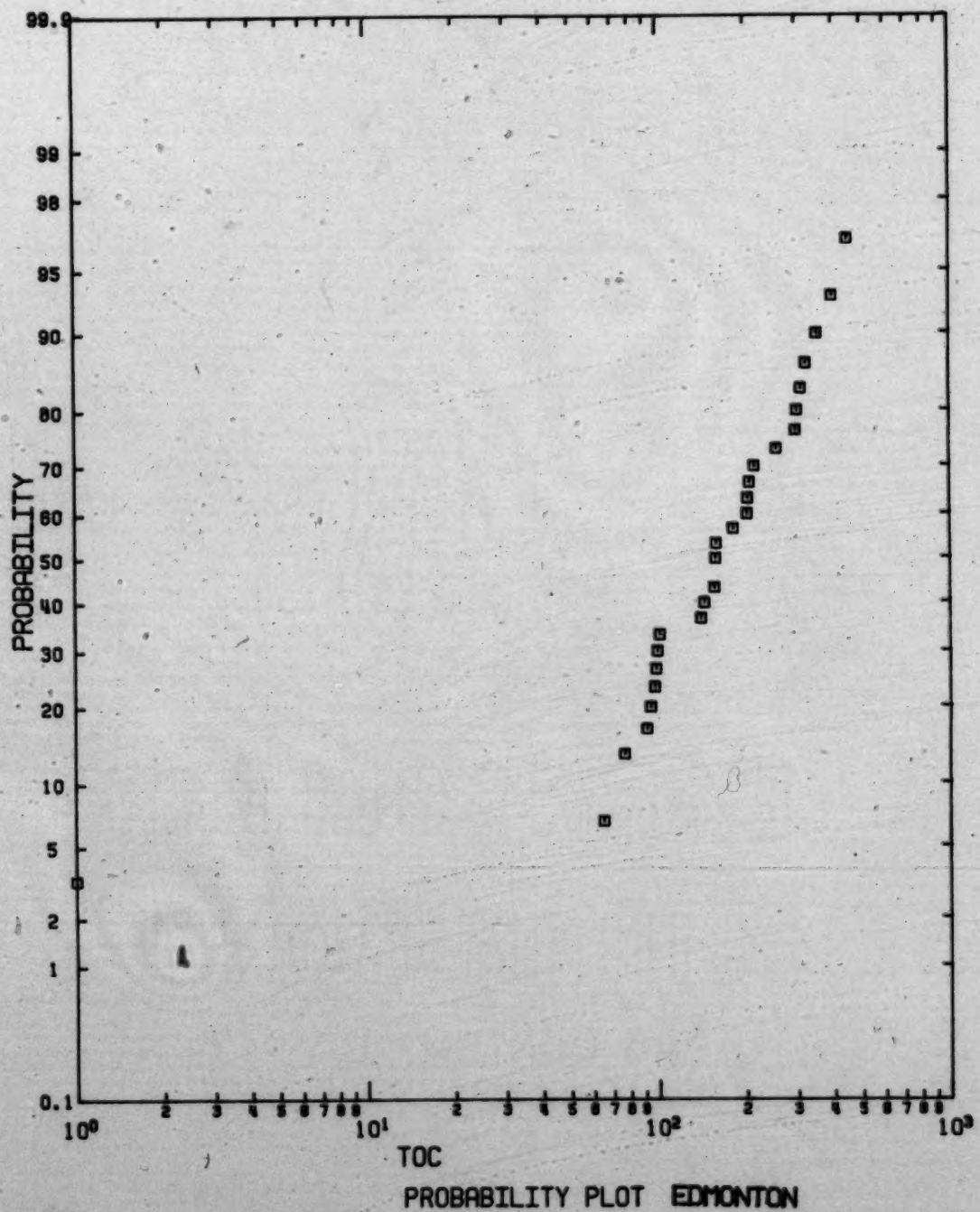
10^3
10^4
10^5
FECAL STREP.
PROBABILITY PLOT EDMONTON

Fig. A27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PROBABILITY
10^0
10^1
10^2
10^3
TOC
PROBABILITY PLOT EDMONTON

Fig. A28

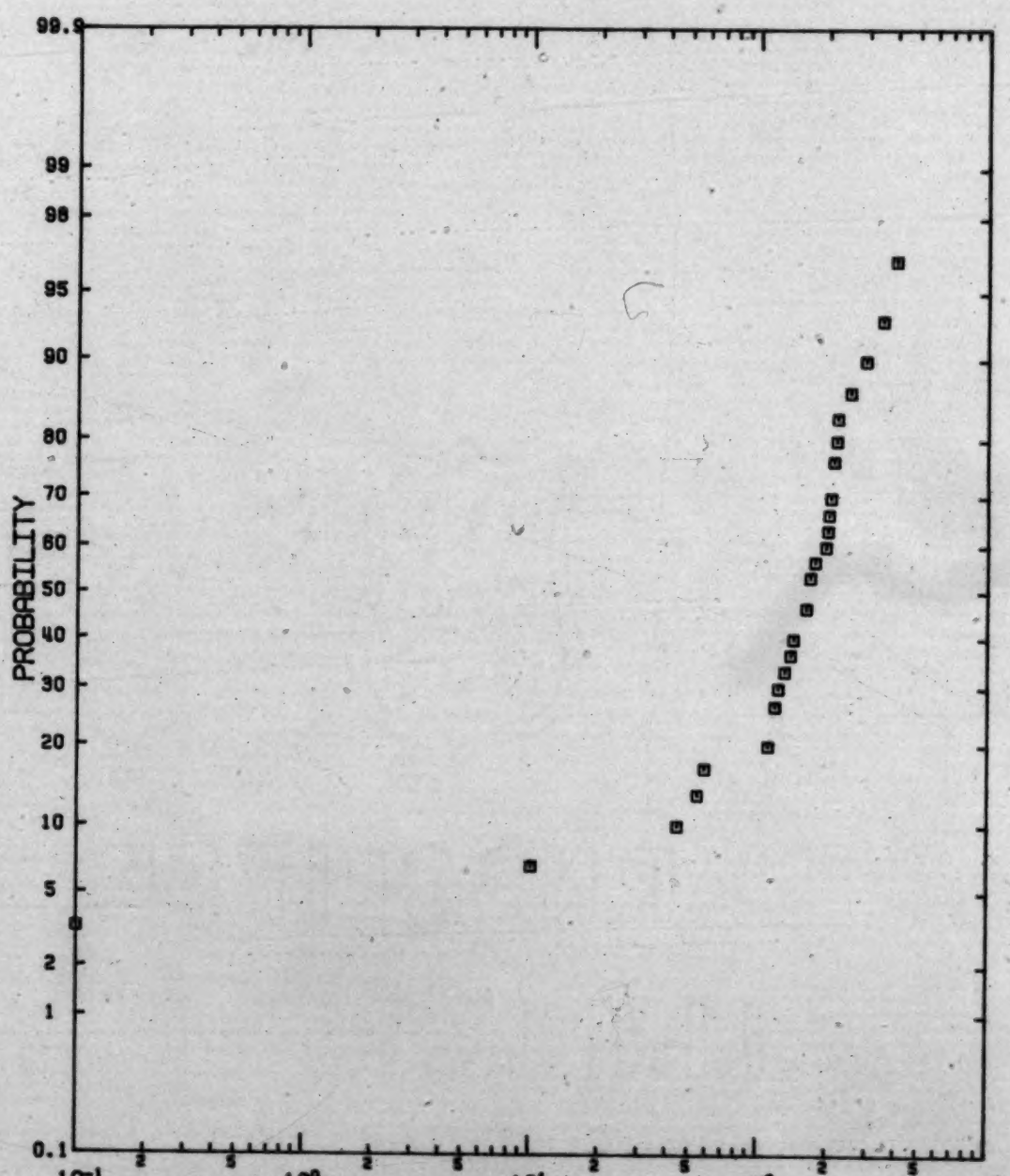
99.9
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.1
PROBABILITY
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
S. SOLIDS
PROBABILITY PLOT EDMONTON

Fig. A29

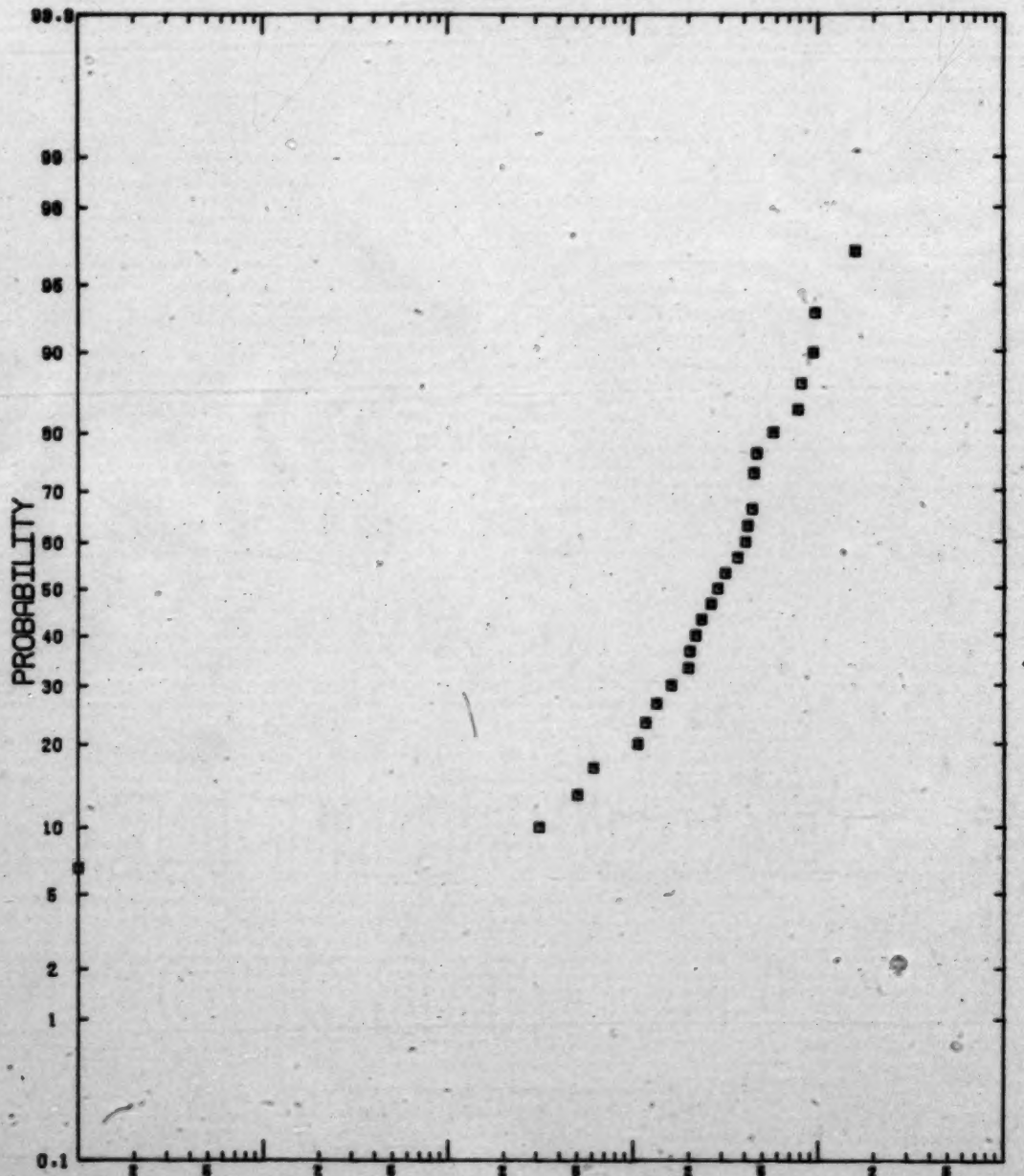
PROBABILITY
99.9
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.1
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
T. PHOSPHATES
PROBABILITY PLOT EDMONTON

Fig. A30

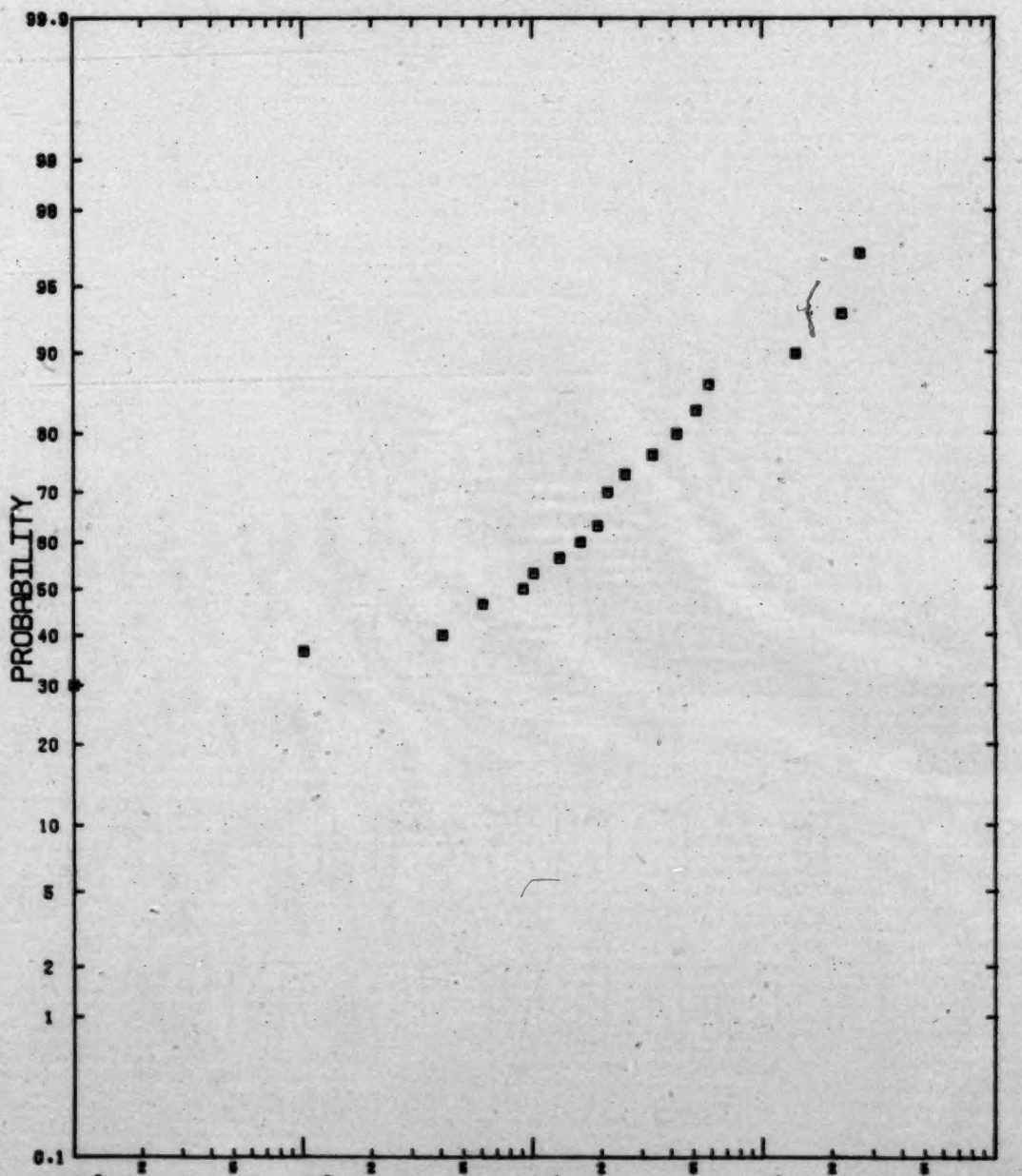
99.9
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.1
PROBABILITY
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
O. PHOSPHATES
PROBABILITY PLOT EDMONTON

Fig. A3I

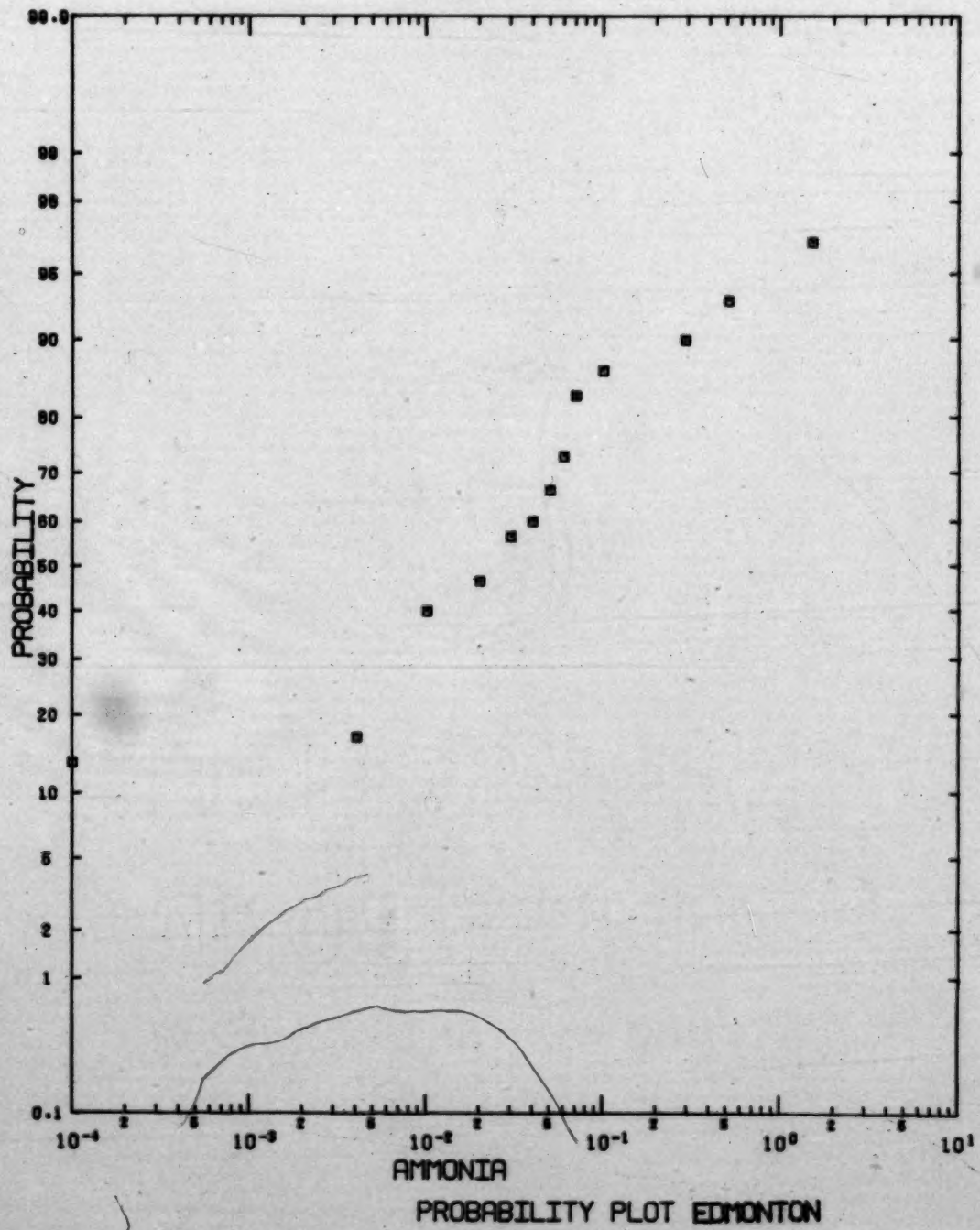
PROBABILITY
99.9
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.1
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
AMMONIA
PROBABILITY PLOT EDMONTON

Fig. A32

Plot of Concentration of Total Coliforms versus Water Usage

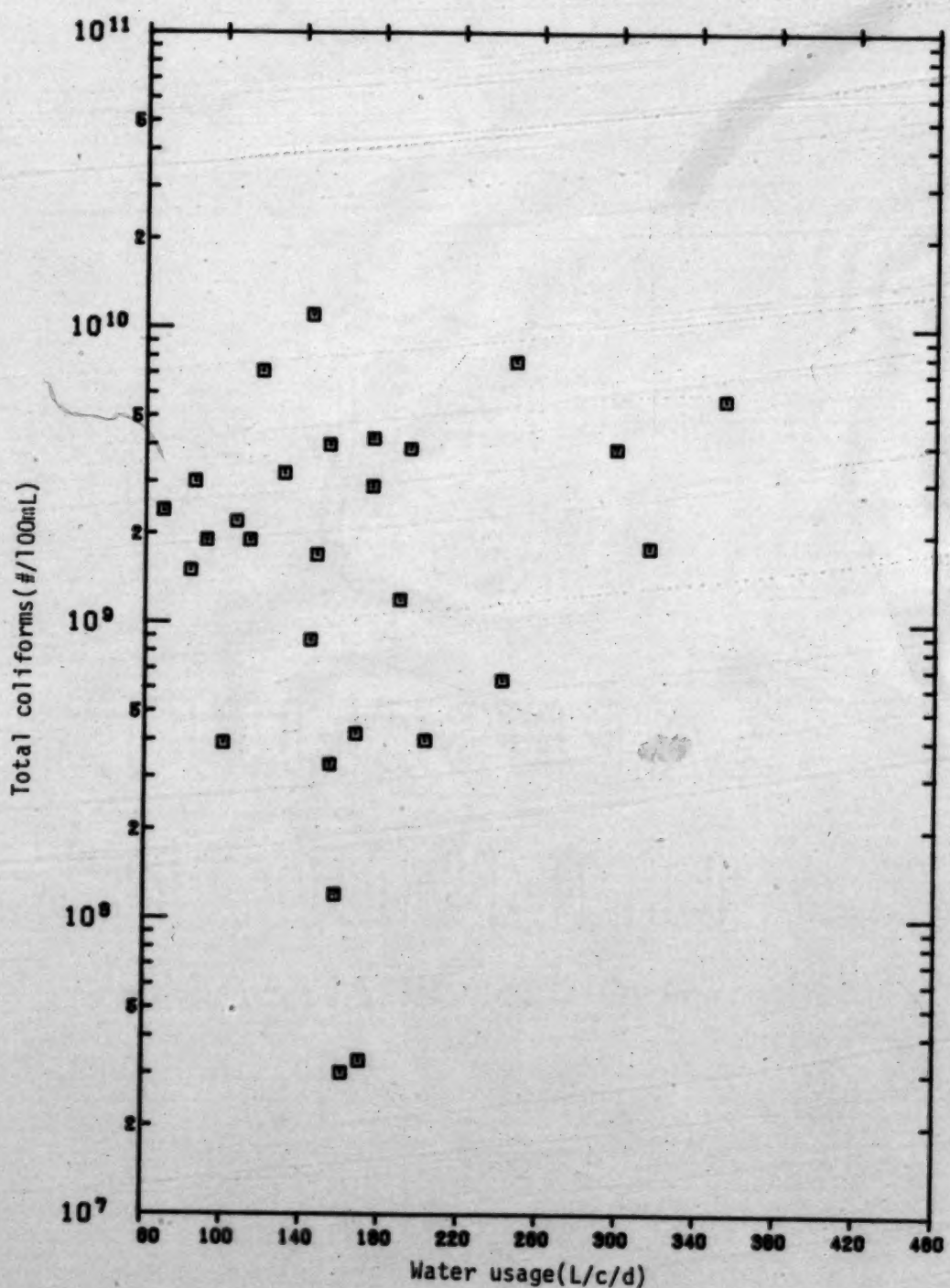

Fig. A33

Plot of Concentration of Fecal Coliforms versus Water Usage

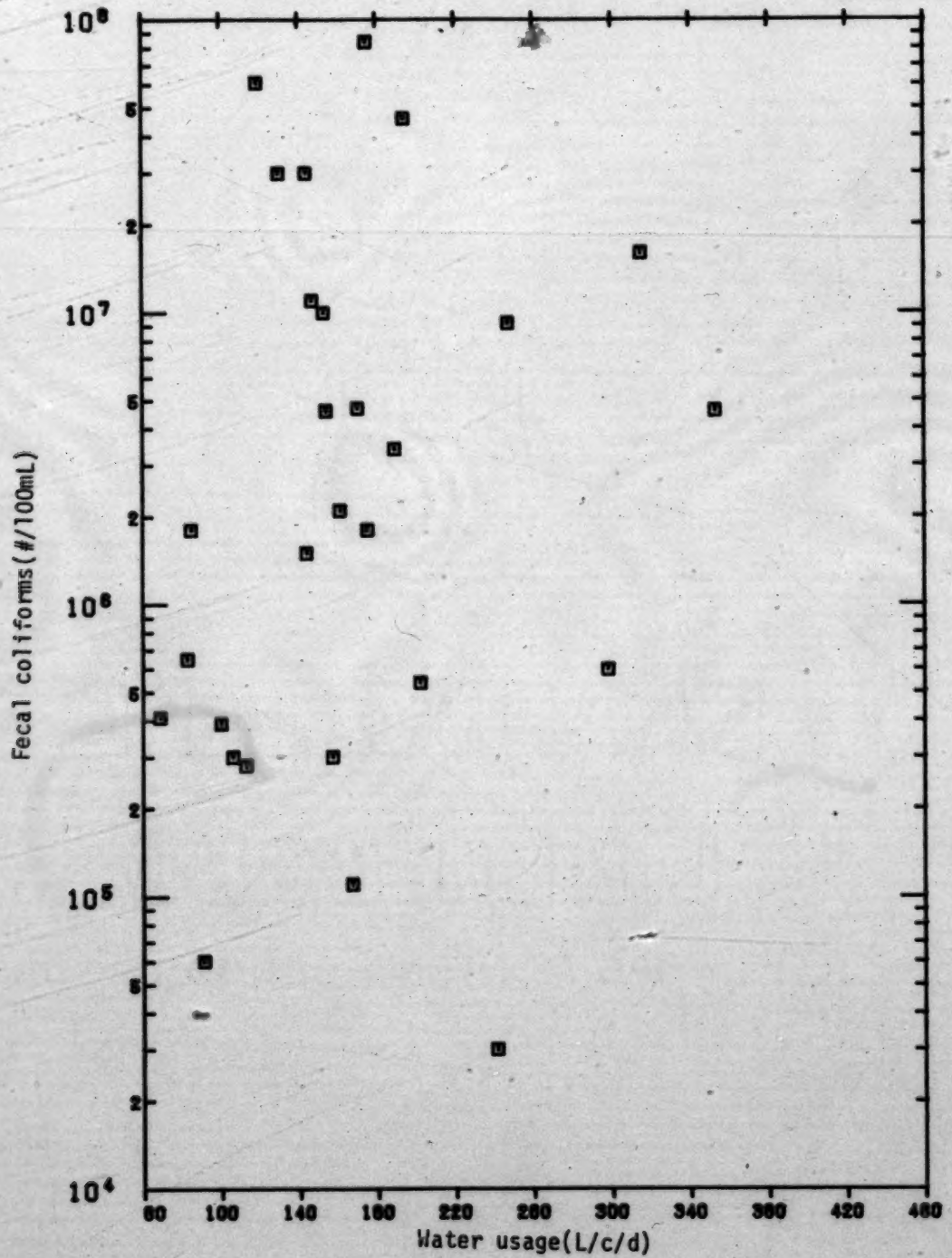

Fig. A34

Plot of Concentration of Fecal Strep. versus Water Usage

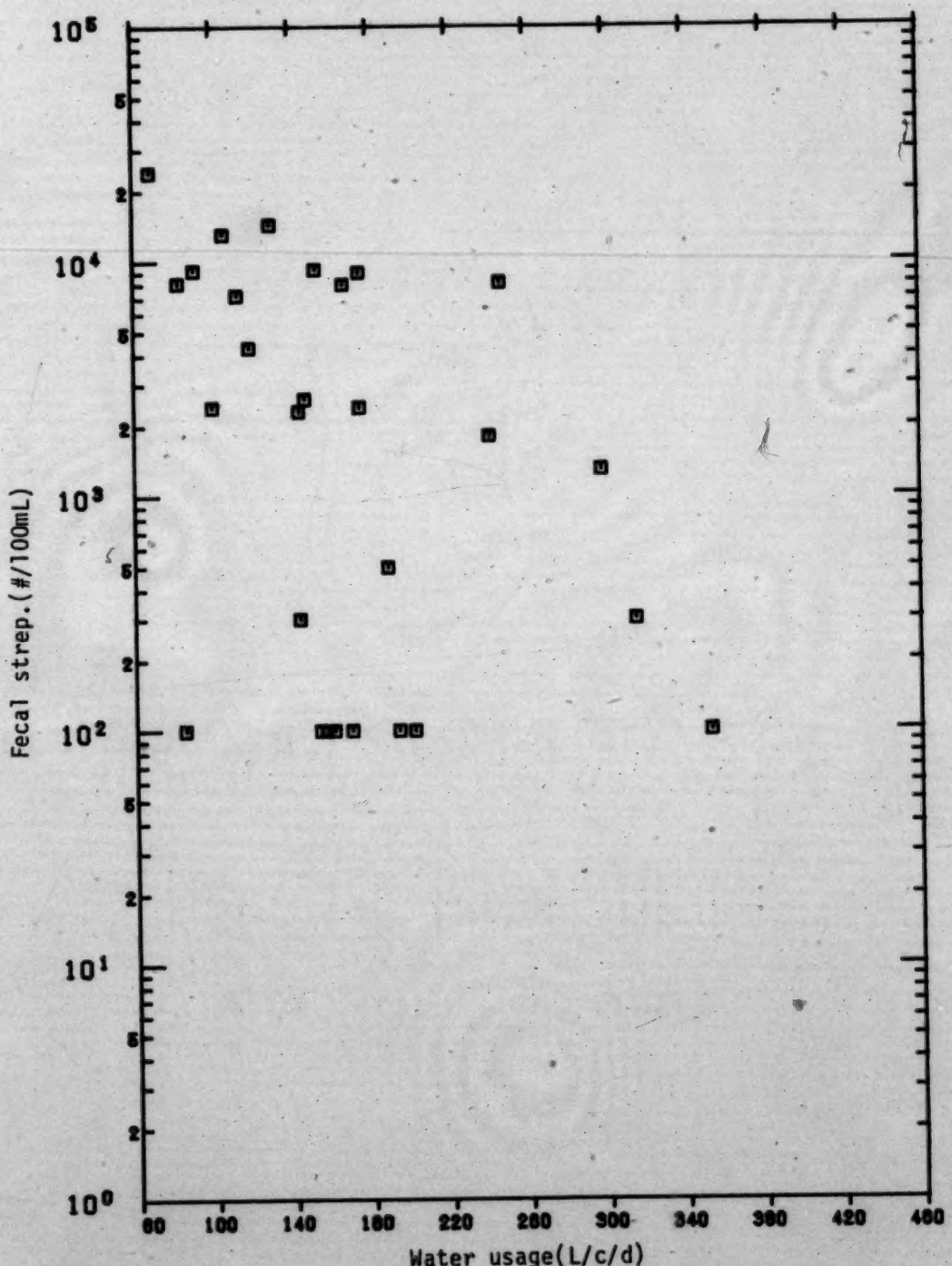

Fig. A35

Plot of Concentration of TOC versus Water Usage

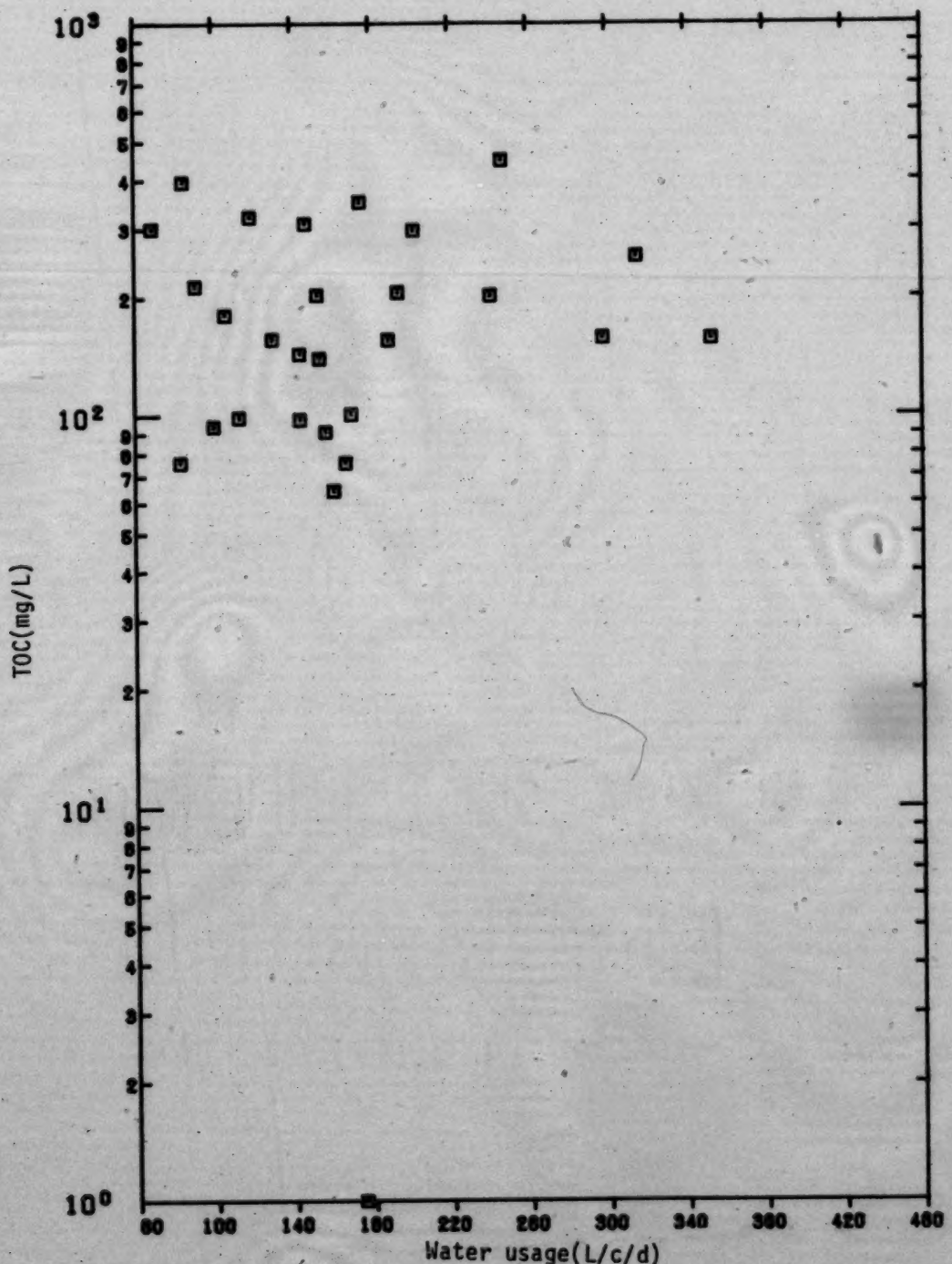

Fig. A36

Plot of Concentration of S. Solids versus Water Usage

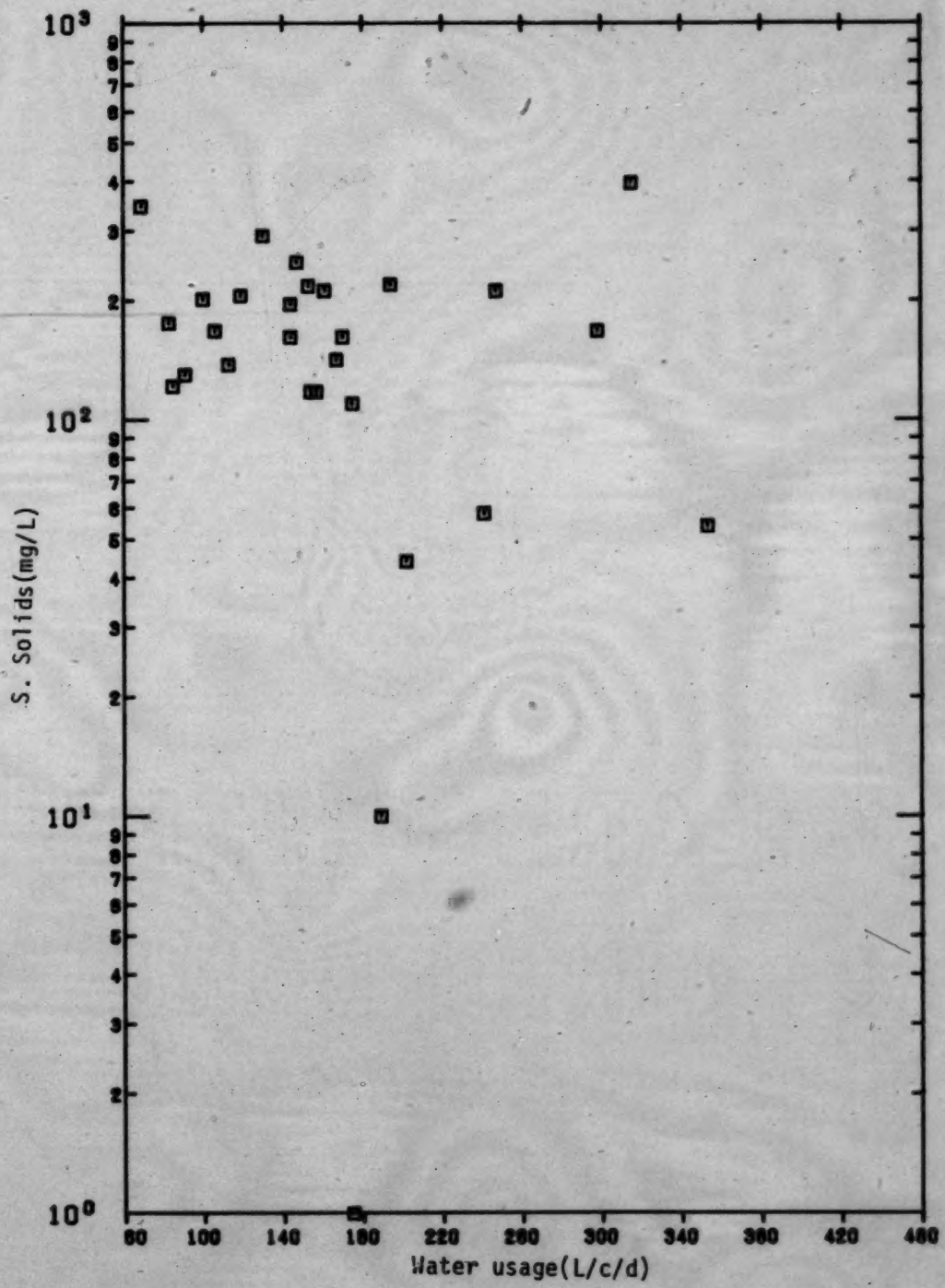

Fig. A37

Plot of Concentration of Total Phosphorus versus Water Usage

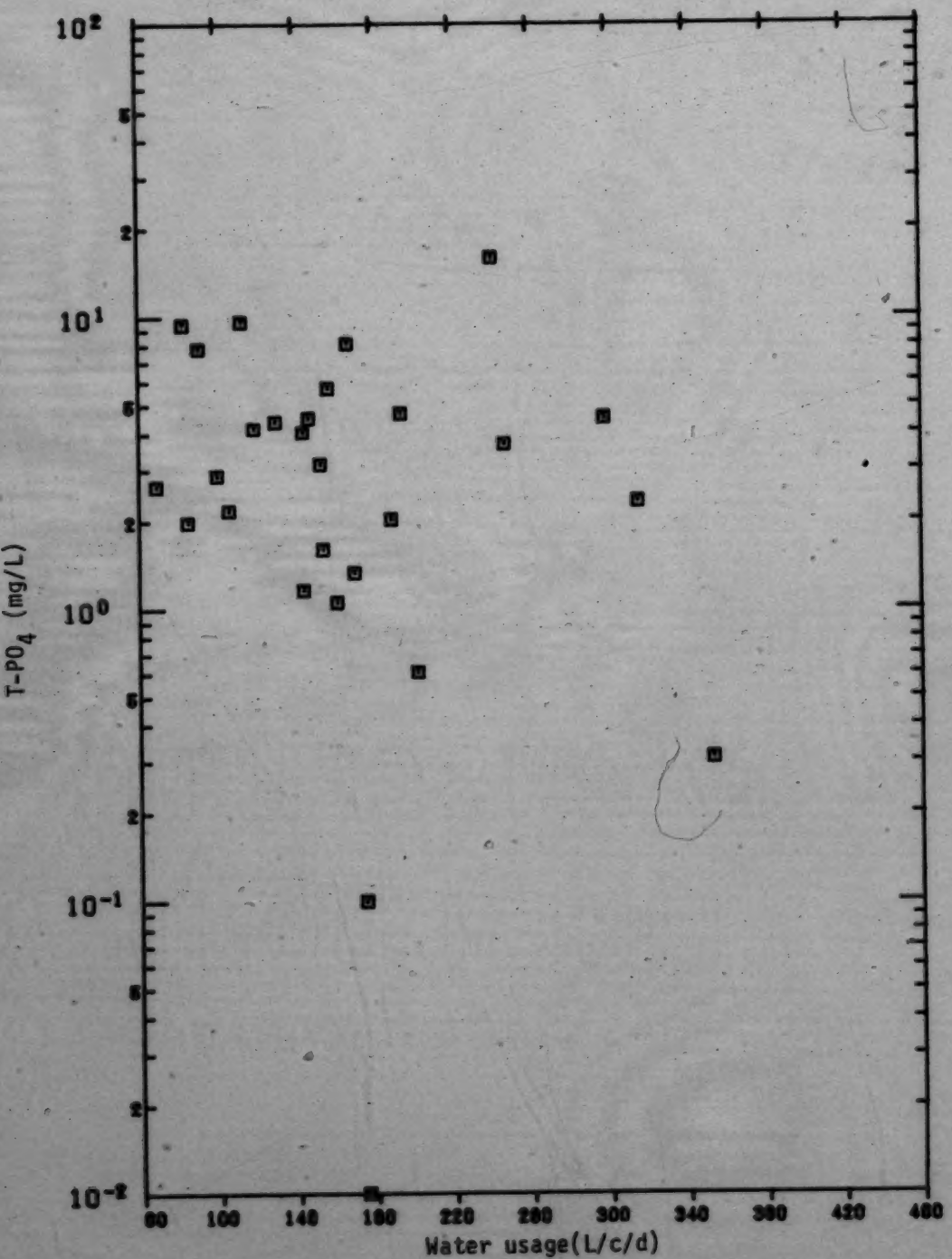

Fig. A38

Plot of Concentration of Ortho Phosphorus versus Water Usage

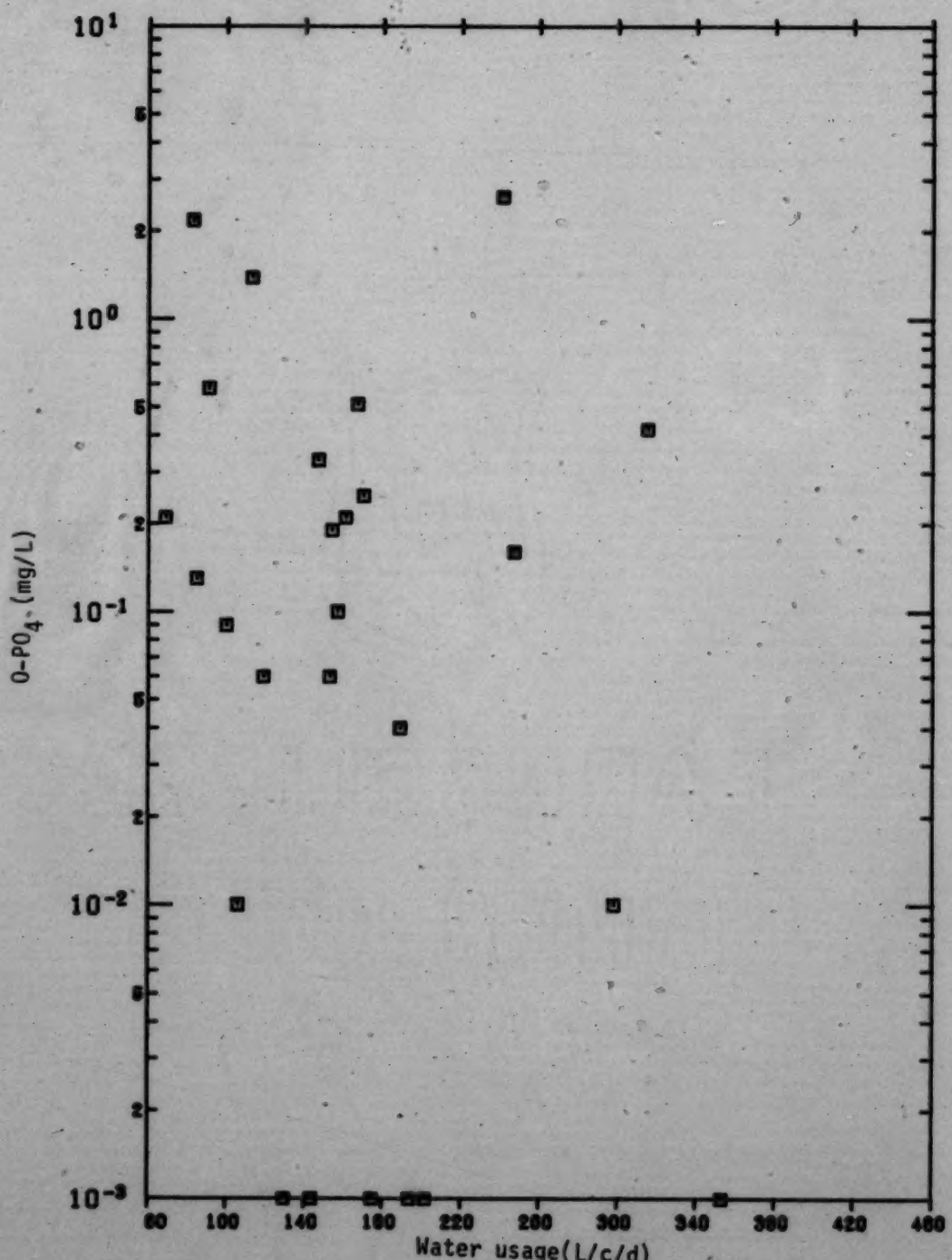

Fig. A39

Plot of Concentration of Ammonia versus Water Usage

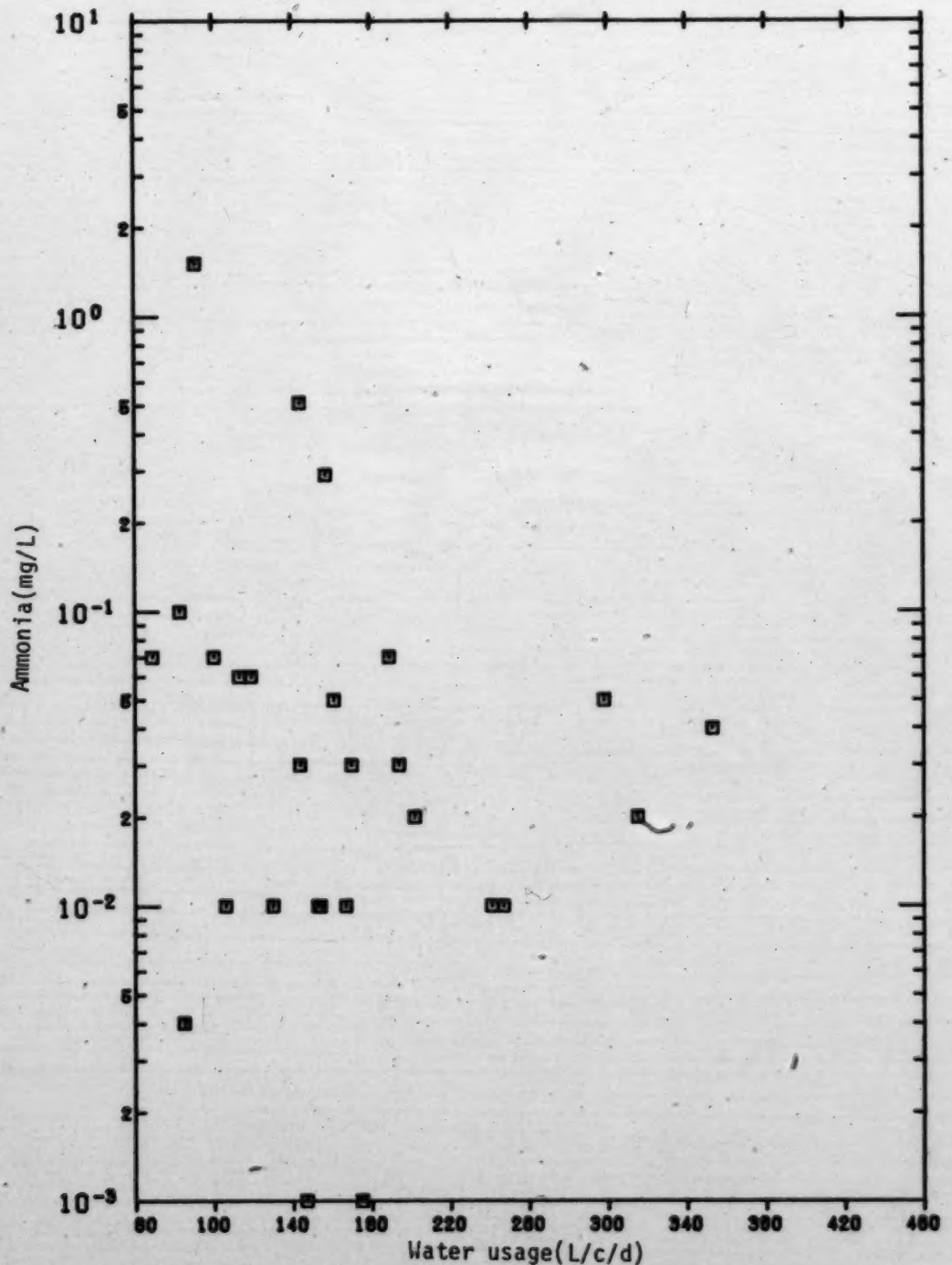

Fig. A40